U. S. Field Artillery Board, Fort Riley.

Gunnery and Explosives

for

Field Artillery Officers

WASHINGTON
GOVERNMENT PRINTING OFFICE
1911

WAR DEPARTMENT.

Document No. 391.

OFFICE OF THE CHIEF OF STAFF.

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF STAFF,
Washington, May 22, 1911.

The following publication entitled "Gunnery and Explosives for Field Artillery Officers," prepared by Capt. William I. Westervelt, Fifth Field Artillery, under the supervision of the Field Artillery Board, Fort Riley, Kans., is herewith published for the information and guidance of the Field Artillery of the Regular Army and the Organized Militia of the United States.

By order of the Secretary of War:

LEONARD WOOD,
Major General, Chief of Staff.

A LIST OF AUTHORITIES CONSULTED IN THE PREPARATION OF THIS VOLUME.

[Those of particular value are marked with a star (*).

IN ENGLISH.

Nitro Explosives. Sanford.
* Essay on Shrapnel Fire of Field Artillery. Rohne.
Artillery Fire. The Battery. Nicholson.
Manufacture of Explosives. Guttman.
* A Primer of Explosives. Cooper-Key.
* Ordnance and Gunnery. Lissak.
* Ballistics. Parts 1, 2, and 3. Hamilton.
The Modern High Explosives. Eissler.
Notes on Dynamics. Greenhill.
* Modern Guns and Gunnery. Bethell.
Field Artillery Fire. White.
* Records of the Field Artillery Board.

IN FRENCH.

Notes sur le canon de 75. Morlière.
* Note sur le Tir Collectif. French Ministry of War.
Manuel de Tir de l'Artillerie de Campagne Allemande. Jung.
Tir Masqué. Touvenin.
* Cours Élémentaire de Tir de Campagne. Tréguier.
Pratique du Tir du Canon de 75 de Campagne. Challeat.
* Tir Masqué. Challeat.
Le Tir de l'Artillerie contre les Batteries à Grands Bouchers. Docquin.
* Le Mécanisme du Tir de l'Artillerie de Campagne à Tir Rapide. Maillard.

Emploi des Feux de l'Artillerie. Percin.
Leçons sur l'Artillerie. Alvin.
* Ballistique Extérieure Rationnelle. Charbonnier.
* Leçons d'Artillerie. Girardon.
Revue d'Artillerie, vols. 63, 68, 69, 70, 71, and 73.
L'Artillerie de Campagne à Tir Rapide et à Boucliers. Campana.

IN GERMAN.

* Die Lehre vom Schuz Gewehr und Geschutz. Heydenreich. Vols. 1 and 2.
Die Explosivstoffe. Brunswig.
* Die Heutige Feldartillerie u. s. w. Roskoten. Vols. 1 and 2.
Lehrbuch der Waffenlehre. Marschner.
Artilleristische Monatshefte, 1907, pt. 2, and 1908, pt. 2.
* Zielerkundung der Artillerie. Seeger.
* Die Richt- und Schiess- Ausbildung der Feldartillerie unter Berücksichtung des Feldartillerie-Gerats. Landauer.
* Die Feuertätigkeit der 8 cm. Feld Kannonen Batterien. Eisner.

TABLE OF CONTENTS.

PART I.

GUNNERY.

PART II.

EXPLOSIVES.

GUNNERY AND EXPLOSIVES FOR FIELD ARTILLERY OFFICERS.

Part I.—GUNNERY.

CHAPTER I.

THE THREE-INCH FIELD ARTILLERY MATÉRIEL.

1. The gun.—The gun with which this text is primarily concerned is the 3-inch field gun. A thorough knowledge of this weapon is of prime importance to the field artilleryman and is to be gained by a study of the Handbook of the 3-inch Field Artillery Matériel. In this study it is essential that reference be made to the gun itself or to other parts of the matériel, for in this way only is it possible to verify concretely the facts set forth in the handbook. It should be borne in mind that, without the gun itself, field artillery has no part to play; for this reason the gun is the initial field artillery conception, to be followed in order by a knowledge of its ammunition, its equipment, and its mobility. A knowledge of the matériel, a proper understanding of its limitations and a keen desire to learn its proper use, are the fundamentals upon which subsequent experience builds the accomplished field artilleryman.

2. General remarks concerning the matériel.—The introduction of smokeless powder and of accurate long range small arms made obsolete the old idea of battle fields. Concealed positions became the rule rather than the exception; changes of position involved speed and a minimum of exposure. The old type of weapon was useless under the new conditions and it was mechanically incapable of taking advantage of the fleeting moments during which an enemy was exposed. The problem of bringing the field artillery weapon up to date was solved when the long-recoil carriage was perfected. On this carriage the gun recoils without objectionable derangement of its laying, returning after firing to a position so near its former one that it may be layed accurately without loss of time.

3. Considerations affecting the design.—Without introducing the idea of mobility, gun power would be the ruling factor in the design of a light-artillery weapon, hence the ordnance engineer would need little more than a reference to his designs of weapons intended for coast defense. Mobility, however, is a factor—an essential one—and for this reason the field-artillery service finds itself restricted to that gun power which may be pulled from place to place by horses. That the power of the horse thoroughly dominates the situation may be discerned in an analysis of the light field artillery of all nations—the matériel is practically standardized. Although it is a fact that the field artillery weapon is limited by questions of mobility, it will be shown that, notwithstanding its necessarily curtailed power, it is rarely if ever used to the full theoretical limit. The questions of ammunition supply, observation of fire, loss of time not attributable to the matériel, etc., enter largely into its practical employment.

4. Power of the weapon.—Shrapnel is the principal ammunition used by the field artillery, and with the adoption of the high explosive shrapnel, or unit projectile, will be the only projectile for the light field weapon. As the particular function of the shrapnel is to carry a number of bullets to a distance from the gun, there to discharge them with killing energy, the gun should be designed with a view to permitting the highest attainable shrapnel efficiency. The 3-inch field gun is admirably suited to the above condition.

The maximum range of a service shrapnel is well in excess of 6,000 yards, up to which point its remaining velocity, when augmented by that due to the shrapnel bursting charge, is sufficient to produce killing effect upon horses and men. The initial velocity of the gun under consideration is 1,700 feet per second. Such velocity is small when compared with that of high-power coast-defense guns, but it is ample for the purpose. Little or no advantage would accrue from higher velocities as the projectile is deficient in power of penetration and too small for serious percussive effect against even temporary entrenchments. The limit of the necessary power of light field artillery has been reached when opposing personnel is being annihilated, when opposing matériel of like power is being destroyed, or when the fire from moderately entrenched positions is being neutralized.

5. Rapidity of fire.—The questions of mobility and power having been treated, some consideration of the speed and facility with which the service weapon performs its function should follow. As

previously stated, the important feature making for rapidity of fire is the return of the gun after firing to its former position. Any small derangement may be corrected by small and quick changes in the traversing and elevating mechanisms. By an examination of the breech mechanism, fuse setter, and readily adjusted devices for laying, it will be seen that the idea of a rapid-fire machine has been mechanically expressed in the service 3-inch field artillery matériel. Fixed ammunition and easily set fuses also contribute to rapid fire.

6. Pointing the gun.—A gun must be pointed in such direction and elevated to such degree that a projectile fired from it will hit the target. In order to regulate the direction, a fixed line is established, and the axis of the gun is given such direction in relation to this fixed line as will result in hits on the target when the gun is properly elevated. The fixed line becomes the line from gun to target in direct laying and from gun to aiming point in indirect laying. The appliances provided for pointing and laying the 3-inch fieldpiece include line sights, the adjustable or tangent sight, the panoramic sight, and the range quadrant, all of which are fully described in the handbook. The sighting apparatus, except in case of the line sights, is attached to nonrecoiling parts of the gun carriage and remains in place during firing. As the carriage does not move, the gunner, with elevating and traversing handwheels conveniently at hand, finds the operation of sighting a continuous one.

The elevation and direction are given by moving the cradle to which the sight and quadrant are attached.

This system does not have the independent line of sight used by the French. In that system the elevation of the gun for range is made above the rocker or top carriage, while the angle of site is set off by moving the top carriage. This method necessitates the setting of an angle of site device for all direct as well as for indirect laying.

Some form of telescopic sight is necessary, in view of the great range of the field gun and for the reason that indirect laying requires a sight permitting rapid laying of the gun when the target is hidden. These two requisites are combined in the panoramic sight, which is a telescopic sight so fitted with reflectors and prisms that the observer, with his eye at an eyepiece fixed in position, may bring into the field of view any object upon the horizon, the image appearing magnified, but otherwise as if viewed directly by the unaided eye. Due to the fact that with the telescopic sight the image of the target or aiming point is in the same plane as the cross

wires, this sight is more accurate than the tangent sight and requires less experience to use.

The range quadrant is for the purpose of setting off the proper range during indirect laying. For direct laying the sights are generally used, but for indirect laying the range quadrant must be used, since the angle of site of an aiming point bears no fixed relation to that of the target.

In order to take full advantage of the great range and accuracy of the service matériel and of the refinements of the sighting arrangements, a battery commander's telescope has been provided. This telescope is of the general form of the panoramic sight, but more powerful, and, with its all-around motion in azimuth and limited motion in elevation, becomes a satisfactory angle-measuring instrument. The scales of the telescope, sights, and range quadrant are so graduated that a reading may be transferred from one instrument to another without computation or reference tables.

The officer conducting the fire is furnished with appropriate observing glasses and with proper equipment for the transmission of his commands.

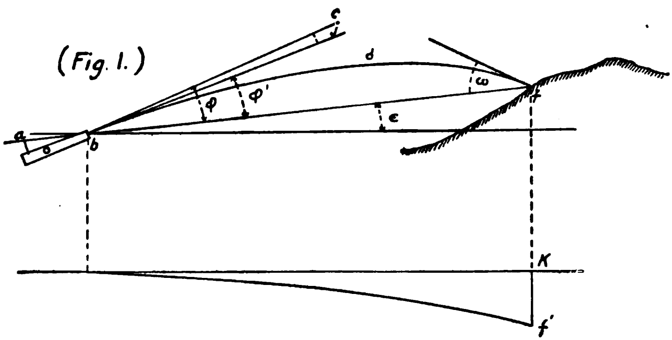
7. Gunnery as applied to field artillery.—The field artilleryman, in the practice of his profession, does not require a great knowledge of the mathematics of gunnery. As a matter of culture such knowledge is desirable, but it should not be sought at the expense of more practical knowledge. The matériel issued for use in the field artillery is the result of thoughtful design and thorough test and may be taken as representative, at least, of the best modern conception of such matériel. A battery of 3-inch field guns is a plant of no small importance, the proper management of which requires intelligence and unflagging zeal. Conditions are such that no absolute criterion of excellence may be established in the case of field batteries. But that battery which has been perfected in fire discipline and whose commanding officer comprehends minutely the purpose of each mechanism of fire and is an adept in applying his knowledge may be said to represent the aim of practical gunnery. Before such an organization can be evolved the matériel itself must be thoroughly understood.

8. Methods of instruction.—The purpose of this text is to suggest such topics as are important to an officer of field artillery. The information contained herein should be augmented by lectures from capable and well-informed instructors and by consulting the authoritative works to which reference has already been made.

Chapter II.

THE TRAJECTORY IN VACUO.

9. Trajectory.—As ordinarily understood by practical artillerymen, the path followed by a projectile during its exterior flight from gun to target is known as its trajectory. Such conception is quite complete in so far as the field artilleryman is concerned, as he has no control over that portion of the projectile's motion termed its interior flight. It will be assumed, therefore, that ammunition issued for use in the field artillery is of such nature that successive projectiles of the same type, fired under the same conditions, will have



(Fig. 1.)

the same trajectory. While the assumption is not strictly correct, as will be shown in a succeeding chapter, yet it is sufficiently true for purposes of discussion and, in the preliminary understanding of firing terms, should be adhered to rigidly.

10. Definitions.—The trajectory, *bdf*, figure 1, is the path of the projectile from gun to target.

The range, *bf*, is the distance from the muzzle of the gun to the target.

The line of sight, *abf*, is the right line passing through the sights and target or aiming point.

The line of departure, *bc*, is the prolongation of the axis of the bore at the instant the projectile leaves the gun.

The plane of fire, or plane of departure, is the vertical plane through the line of departure.

The angle of site, or angle of position, ε, is the angle made by the line joining gun and target with the horizontal.

The angle of departure, ϕ, is the angle made by the line of departure with the line joining gun and target.

The quadrant angle of departure, $\phi+\varepsilon$, is the angle made by the line of departure with the horizontal. This is greater than the angle of departure when the target is above the horizontal and smaller when the target is below the horizontal.

The angle of elevation, ϕ', is the angle between the line joining gun and target and the axis of the piece when the gun is laid.

The jump, j, is the angle between the line of departure and the axis of the gun before firing. The gun and its carriage are made up of elastic parts which yield to a slight extent under the action of the firing stresses, the resulting effect being a small displacement of the axis of the piece after firing. The angle of departure is usually greater than the angle of elevation.

The point of fall, or point of impact, *f*, is the point at which the projectile strikes.

The angle of fall, ω, is the angle made by the tangent to the trajectory with the line joining gun and target at the point of fall.

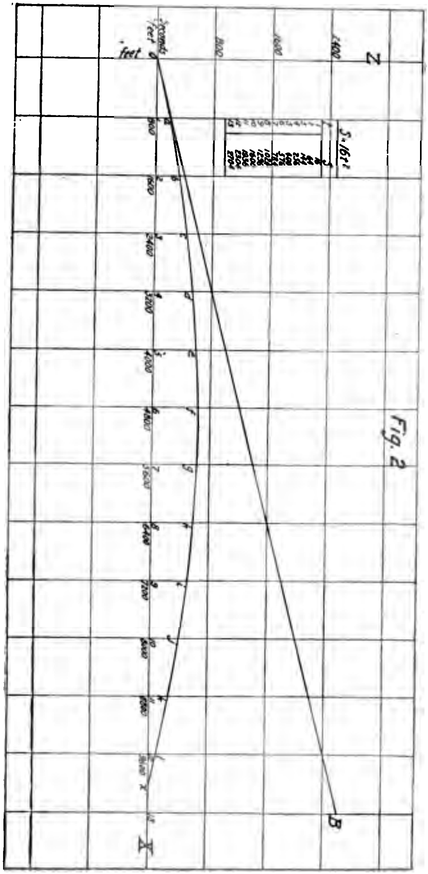
Initial velocity is the velocity of the projectile at the muzzle.

Remaining velocity is the velocity of the projectile at any point of the trajectory.

The drift, *kf'*, is the departure of the projectile from the plane of fire, due principally to the resistance of the air and to the projectile's rotation.

11. The trajectory in vacuo.—In order to understand the trajectory in air the motion of a projectile in vacuo will first be considered. Under this assumption all the variable incidents of service firing are avoided and the mind is left at liberty to form a conception of the path followed by a mass projected into space and acted upon by the earth's attraction solely. The projection into space is accomplished through the action of the expanding gases of the propelling charge, which action imparts velocity to the projectile. This velocity

is known as the initial or muzzle velocity and is measured in feet per second. By assigning a definite value to the initial velocity and knowing the direction of motion at its origin, the trajectory in vacuo becomes determinate and can be easily plotted. At this period of the discussion it should be noted that until the direction of motion is assumed the problem remains indeterminate. This direction of motion is referred to a right line joining both ends of the trajectory, and makes with it an angle known as the angle of departure.



THE TRAJECTORY IN VACUO, ILLUSTRATED GRAPHICALLY.

At the origin of the motion about to be considered, let it be assumed that the projectile has a velocity of 824.6 feet per second along the line OB (fig. 2), making an angle of 14° 2′ 10″.1 with the horizontal *OX*. This would be 800 feet per

second in a horizontal direction and 200 feet per second in a vertical direction. OZ is normal to OX and the trajectory $OabcdX$ lies in the vertical plane XZ. The discussion of the trajectory in vacuo presupposes that the only forces acting is that of gravity—hence the laws of gravity apply.

It is known that a body falling freely drops a distance of approximately 16 feet in the first second after gravity begins to act. Thereafter the distance increases according to the following formula:

$$S \text{ (distance dropped)} = 16t^2$$

in which t stands for the number of seconds during which the body has been falling under the action of gravity.

Referring to figure 2, it will be seen that except for the action of gravity the projectile would have proceeded along its original right line of departure, OB. According to the law, however, its position at the end of any assumed second will be $16t^2$ feet below the line of departure. The problem is solved graphically in figure 2.

It is generally known that a mass falling from rest under the action of gravity will cover a space of 16 feet in the first second. This can be demonstrated practically by dropping a stone and timing its fall. It will be found that the stone will drop 64 feet in 2 seconds and 144 feet in 3 seconds.

From these facts we may proceed to the analysis of the relations existing between falling bodies and the earth. Under what conceivable law will a mass fall 16 feet in 1 second, 64 feet in 2 seconds, and 144 feet in 3 seconds? Certainly its velocity or speed can not be uniform, for during the second second it falls 48 feet and during the third second it falls 80 feet. We therefore reach the conclusion that a falling body gains speed as it falls. We know that the body which starts from rest or zero velocity falls 16 feet in the first second, hence during this second it must have averaged a velocity of 16 feet per second, or must have acquired at the end of this second a velocity of 32 feet per second. In the second second, since a force has the same effect on a body at rest or in motion, it again drops 16 feet due to gravity; but it also drops 32 feet due to the velocity it had at the end of the first second, or 48 feet. The body falls three times as far in the second second as it does in the first second, hence its average speed during this second is 48 feet

per second; since it started with a velocity of 32 feet per second at the beginning of the second second, it must have acquired a speed of 64 feet per second at the end of the second second in order to have averaged 48 feet per second during that second. It will be seen, therefore, that a falling body has a variable speed which increases at the rate of 32 feet per second and that the velocity at any time may be found from the following formula:

$$V \text{ (velocity at any time)} = 32\, t$$

in which t stands for the number of seconds during which the body has been falling under the action of gravity. If the body had velocity before gravity commenced to act it must be considered also. For instance, if a body is thrown vertically downward at a speed of 500 feet per second, at the end of the first second its speed will be 532 feet per second. Conversely, if a body is projected vertically upward at a speed of 500 feet per second, at the end of the first second its speed will be 468 feet per second; in other words, gravity adds to or subtracts from already existing vertical velocity at the rate of 32 feet per second.

A study of figure 2, in connection with the above remarks will reveal the simplicity of the application of the law of gravity. For instance, the particular projectile considered has an initial velocity of 200 feet per second in the upward vertical direction; gravity takes away from this velocity 32 feet per second, hence, in two hundred divided by 32, or 6¼ seconds, the projectile will have no upward velocity and will be found at the summit or topmost point of its trajectory.

In a similar way it may be shown that the total time of flight is 12½ seconds, and that the range is 10,000 feet.

12. Rigidity of the trajectory.—According to the principle of the rigidity of the trajectory, which can be demonstrated mathematically, the relations existing between the trajectory and the line representing the range, are sensibly the same whether the range be horizontal or inclined to the horizon, provided that the quadrant angle of departure is small. That is to say that, considering $\phi+\epsilon$, as small, in figure 1, if the trajectory bdf and the range bf were revolved about the point b until bf were horizontal, the relation of the trajectory to bf would not change. A trajectory calculated for a hori-

zontal range equal to *bf* would then answer as the trajectory for the actual inclined range *bf*. In other words, if the angle of departure necessary to reach a certain point at a horizontal range, x, from the gun and on the same level, is known, it will only be necessary in order to reach another point h feet below the former and at the same horizontal range, x, to subtract from the first angle of departure the angle of site.

It follows from this principle that, within reasonable limits, the trajectory is subservient to the will of the officer conducting the fire. The action of a fire hose throwing a stream of water under constant pressure is a homely but useful conception of what may be done with the trajectory of guns firing at comparatively small quadrant angles of departure.

Chapter III.

THE RANGE TABLE.

13. The trajectory in air.—Due to atmospheric resistance to the projectile's motion, the trajectory in air differs from the hypothetical trajectory in vacuo. A proper conception of the latter assists in understanding the former. Motion in a resisting medium is merely a modified form of unresisted motion and, though its laws may be somewhat complex, yet, for any set of conditions to be met with in practice, they are readily deduced. Fired with the same angle of departure, a projectile resisted by the air will have a shorter range than the projectile in vacuo; the latter has no force acting upon it except that vertically downward and due to gravity, whereas the former is continuously retarded by the pressure of the air in front of it and the friction of air on its sides. In the table below will be found a comparison of certain elements of the trajectory in air with the trajectory in vacuo. The information concerning the trajectory in air is taken from the range table (Appendix B). The trajectories in vacuo have been computed for the five angles of departure corresponding to ranges in air of 1,000, 2,000, 3,000, 4,000, and 5,000 yards.

	Angle of departure.		Muzzle velocity.	Range.	Maximum ordinate.	Time of flight.
	°	′	*Ft. sec.*	*Yards.*	*Feet.*	*Secs.*
Air	1	11.2	1,700	1,000	17.3	2.07
Vacuo	1	11.2	1,700	1,245	19.4	2.20
Air	2	56.7	1,700	2,000	93.1	4.46
Vacuo	2	56.7	1,700	3,089	119.2	4.75
Air	5	12	1,700	3,000	257.0	7.83
Vacuo	5	12	1,700	5,434	370.9	9.63
Air	7	54.2	1,700	4,000	536.0	11.25
Vacuo	7	54.2	1,700	8,200	853.8	14.61
Air	11	10.1	1,700	5,000	975.0	15.12
Vacuo	11	10.1	1,700	11,440	1,694.0	20.58

Some idea may be formed of the resistance of the air, when it is seen that a range of 8,200 yards in vacuo corresponds to 4,000 yards in air.

14. Range tables.—Range tables set forth in a convenient form certain facts pertaining to the trajectory of a projectile in air. Such tables are usually based upon actual firing at the proving grounds. For instance, the shrapnel range table (Appendix B) was prepared approximately as follows: A sufficient number of shrapnel fused with the service fuses of the same lot were secured for the test. Ten rounds each were fired to burst on impact at ranges of approximately 1,500, 2,500, 3,500, 4,500, and 5,500 yards and all the incidents of firing were carefully observed. The angles of departure and the muzzle velocities of the rounds in each group were as nearly as possible the same. The ranges were accurately measured and at the close of the firing it became known that certain angles of departure would assure certain horizontal ranges. Having five ranges accurately determined by firing, the range table was completed by interpolation according to known mathematical methods. The range table is the basis for graduation of the rear sight and the range quadrant. The probable behavior of fuses, which ordinarily are supposed to be adjusted so as to burst in air, is likewise determined by experiment, as the graduations on the fuse and on the fuse setter depend upon the range of a shrapnel to its bursting point.

15. Range table for 3-inch field gun.—An examination of the range table for the 3-inch field gun will show the plan of its construction. The ranges are tabulated for every 100 yards up to and including 6,500 yards, and are the horizontal ranges corresponding to the proper angles of departure, conditions being normal. By "normal conditions" is meant:

That the gun is on the same level as the target.

That the muzzle velocity is 1,700 feet per second.

That each projectile is an exact duplicate of all others.

That there is no wind.

That a standard barometric condition prevails during the firing for range data.

There will be departures from the ideal conditions. Theoretically, such departures should be considered during firing, but practically the necessary corrections are applied boldly at first, and then more carefully until the final laying of the piece and the setting of the fuze give the results desired. For instance, on a windy day when the

barometer reading is high and the thermometer low, the officer conducting the fire would avoid the consideration of each individual departure from normal conditions, by changing the angle of departure, the deflection of his piece and the setting of his fuses, until his observation indicated satisfactory range, direction, and height of burst.

In the field reference to a table will be rare, as the instruments used in laying the gun for elevation and direction and for fuse setting have been designed to express mechanically the facts given in the range table.

16. Angle of departure.—The second and third columns in the range table set forth the angle of departure corresponding to each tabulated value of the range. This angle is made up of the proper elevation for the horizontal range considered plus the angle of jump, which latter angle increases as the angle of elevation of the piece is increased. In measuring the angle of jump the gun carriage is placed upon a platform, the quadrant angle of elevation carefully applied to the piece, which is then fired. A screen of paper placed at a known distance in front of the gun and away from the effect of the blast will show the hole made by the projectile. It will be found that the center of the hole is above the line passing through the axis of the piece before firing. Knowing the proper distance from gun to screen, the jump may be computed.

17. One minute, in yards of range.—The fifth column of the range table is of interest as indicating the error in range which may be expected from an incorrect laying for elevation. The value in range of one minute in the angle of departure decreases with the range. The sixth column gives similar information in terms of mils.

18. $\triangle$ X for $\pm$10 f. s. M. V.—As stated before, the range table is based upon a muzzle velocity of 1,700 feet per second. Any variation in this velocity causes a corresponding increase or decrease in the range. As ammunition is issued to the field artillery in rounds already made up ready for firing, variations in muzzle velocity can not ordinarily be attributed to improper handling by troops. However, care must be taken not to allow a round of ammunition to remain in the bore of a gun which has been heated by firing, as an increase in temperature of the powder before firing will raise the muzzle velocity. The round of ammunition should be handled with reasonable care to avoid rupturing the igniting charge of black powder. The rotating band should be protected from mutilation and the bore of

the gun should be kept reasonably clean. Further than these precautions, it is not practicable in the field to take account of variations in muzzle velocity. The effect of such variations are corrected by the bracketing system.

19. $\triangle$X for $\triangle$C=±1/10.—C is the ballistic coefficient of the projectile under the assumed conditions of firing. A variation in these conditions produces a corresponding variation in C. It must be understood that firing is rarely conducted under the conditions upon which the range table is based. The range table standard barometric height, thermometer reading, etc., do not exist in actual practice except as a matter of chance. An examination of this important factor in the formula for the range should be interesting.

$$C=\frac{\delta_1}{\delta}\cdot\ \frac{w}{\beta c.d^2}$$

in which,

δ_1 is the standard or range table density of the air.
δ the density for the time considered.
βc the coefficient of reduction.
d the diameter of the projectile in inches.
w the weight of the projectile in pounds.

It will be seen, therefore, that C will change whenever δ, βc, d, and w change; d and w are the diameter and weight, respectively, of the service 3-inch projectile, and may be assumed not to vary; βc is a coefficient determined by experiment with the particular kind of projectile, and may be assumed to remain constant. The principal variation in C is therefore due to δ or changes in atmospheric conditions. Tables have been prepared from which, knowing the height of the barometer and the temperature, $\frac{\delta_1}{\delta}$ may be computed. It will be seen that as δ decreases C increases, and as the range depends directly upon the value of C, such range will be greater as δ becomes less. Where firing is more or less continuous throughout the day marked changes in range for the same laying are apt to be noted, but, like variations due to muzzle velocity, the changes are corrected in the bracketing process and no computation is necessary for them in the field.

20. $\triangle$X for wind.—The ninth column of the range table shows the effect of a 10-mile wind blowing up or down the range. This column is based on the assumption that the wind is blowing constantly at the assumed rate.

21. Drift.—The service projectile leaves the muzzle of the gun with a velocity in the direction of the trajectory and a motion of rotation about its longer axis. This rotation is impressed upon the projectile during its interior flight, and is for the purpose of steadying or stabilizing its subsequent progress. The effect of the resistance of the air on the rotating projectile is a movement of the projectile out of and to the right of the plane of fire. This departure, kf' in figure 1, is called drift.

In order to lay for direction, the amount of motion of the projectile out of the plane of fire should be known. This information is tabulated in the tenth and eleventh columns of the range table. Ordinarily the deflection is not greatly affected due to wind and drift, and in practice the amount of such correction is estimated. The empirical rules contained in Field Artillery Drill Regulations are sufficiently accurate for all practical purposes.

22. Angle of fall.—The twelfth and thirteenth columns of the range table contain information concerning the descending branch of the trajectory. The value of this information will become apparent when the subject of shrapnel fire is taken up.

23. Time of flight.—The fourteenth column of the range table contains the times of flight corresponding to the tabulated ranges.

24. Terminal velocity.—The fifteenth column of the range table contains the terminal velocities. An increased velocity of about 250 feet is imparted to the shrapnel balls by the bursting charge; hence it will be seen that, based upon a killing velocity of 400 foot-seconds for men and 880 foot-seconds for horses, the terminal velocity at the maximum recorded range is ample.

25. Maximum ordinate.—The last column contains the maximum ordinate corresponding to the tabulated range. These ordinates have been computed by methods set forth in exterior ballistics and are the vertical distances from the horizontal range to the summit or highest point of the trajectory. A convenient approximate formula for the maximum ordinate is:

$$h=4t^2$$

in which h is the maximum ordinate in feet and t the corresponding time of flight in seconds. The range to the maximum ordinate is approximately that range corresponding to an angle of departure half as great. For instance, the angle of departure corresponding to a range of 6,500 yards is 17° 12′6; one-half of this angle is 8° 36′3 which corresponds to a range of 4,250 yards.

26. General remarks.—As previously stated in this chapter, in the field reference to the range table will be rare. The instruments of precision, without which the battery is in an unequipped state, are themselves constructed in such manner as to make the use of the range table in the field almost wholly unnecessary. These instruments are the sights, the range quadrant and the fuse setter, descriptions of all of which may be found in the handbook. The gun and ammunition will respond, within reasonable limits, to any changes made in the laying for range and direction; the time burst of the fuse may be varied at will, hence from a practical viewpoint all that is needed in the field is a firing unit properly equipped, together with ample ammunition for adjustment of fire and subsequent fire for effect. The results obtained will then depend upon the handling of the equipment by the personnel.

The theoretical study of the range tables by officers is, however, necessary in order that they may acquire a sound understanding of the practical uses of the matériel as laid down in the Drill Regulations, and to lead to progress and improvement in methods and matériel.

CHAPTER IV.

AMMUNITION FOR THE LIGHT FIELD GUN.

27. Classification.—The ammunition available for use with the 3-inch field guns at present is of three kinds, i. e., common shrapnel, high-explosive shell, and high-explosive shrapnel. Shrapnel is the principal projectile of our present field artillery and in the form of high-explosive shrapnel will become the only projectile within a short time.

28. Common shrapnel.—The construction of the common shrapnel is described in the handbook. An examination of the design will show that the modern shrapnel is a projectile which carries a number of bullets to a distance from the gun, where they are discharged with killing energy over an extended area. The shrapnel is made of an exceptionally strong drawn steel case, which remains intact upon the explosion of the bursting charge. Formerly the shrapnel case ruptured at the instant of time burst, hence failed to give the accurate spread of bullets so easily noticeable in the more recent product. For the purpose of facilitating observation of fire a portion of the matrix surrounding the shrapnel balls is of smoke-producing material. The advantage of having a point in the shrapnel's trajectory made visible, as well as being able to observe some of the dust thrown up by the balls upon impact, is obvious.

The fuse used in the shrapnel is the F. A. 21-second combination fuse, model of 1907, and is arranged so that if the projectile fails to burst in flight it will burst upon graze or soon after. The fuse may be set at zero, whereupon the shrapnel will burst at about 20 feet from the muzzle of the gun. The common shrapnel is essentially a projectile for attacking personnel and has little or no effect against walls or even light entrenchments. Used in an attack of a fieldwork of even temporary type, its function is to keep down the defenders until our infantry can advance sufficiently to warrant a rush on the position.

NOTE.—As a matter of interest to field artillery officers and to officers of infantry, and particularly for the benefit of those officers who recall the almost hopeless irregularity of action of the old type of fuse, the following results of firing with the model 1907 fuse are quoted:

REGIMENTAL PROBLEM.

On November 8, 1910, the regimental commander of the Sixth Field Artillery conducted the fire of his regiment against a line of trenches represented by 490 kneeling

figures at a range of 2,200 yards. It was supposed that friendly infantry was advancing against the trenches, hence there were three lines of standing and kneeling figures at 100 yards, 200 yards, and 300 yards from the enemy's trenches. There were 320 figures in the friendly lines.

The ammunition used was common shrapnel, fused with the model of 1907 fuse. In the enemy's trenches 358 out of 490 figures were hit—an average of 73 per cent. In the advancing infantry only 3 figures were hit—all on left of line nearest target. In all there were 140 rounds fired.

29. High-explosive shell.—Due to the fact that common shrapnel was without sufficient effect when used against walls, trenches, light cover, and the enemy's matériel, it became necessary to adopt a high-explosive shell. The shell bursts upon impact against the obstacle or after having penetrated. In theory the shell is merely the vehicle for the transportation of some high explosive to be made effective upon impact. As a matter of fact the quantity of high explosive in a 3-inch shell is so small that the effect of detonation is much less extensive than might be supposed. A typical use of high-explosive shell is found in its employment against the guns of an opponent's battery which has been silenced temporarily as the result of overpowering shrapnel fire.

High-explosive shell may be used to demolish overhead and head cover as a preparation for subsequent shrapnel fire.

30. High-explosive shrapnel.—Notwithstanding the fact that shrapnel is the principal projectile for the field artillery, it will be seen that certain functions of the high-explosive shell are also necessary. The high-explosive shrapnel has been designed to embody as fully as possible the good features of the common shrapnel and the high-explosive shell. The high-explosive shrapnel, without fuse, is practically the same as the common shrapnel, so far as its construction goes. Actually the only essential difference is the substitution of an active for an inert matrix. The matrix surrounding the balls in a common shrapnel is resin and mono-nitro-naphthalene; in the high-explosive shrapnel the matrix is tri-nitro-toluol, a high explosive.

The fuse of the high-explosive shrapnel, in so far as the time action is regulated, is the same as the present field artillery 21-second combination fuse, model 1907. The essential difference is that for the percussion-ignition effect in the common shrapnel fuse a percussion-detonation effect has been substituted. The difference between the two effects will be considered in a chapter on explosives.

The high explosive shrapnel affords the following advantages:

(*a*) It is a single-type projectile, hence obviates the difficulty of supplying two forms of ammunition. Heretofore much discussion

has taken place regarding the proportion of shell to shrapnel. The problem, though indeterminate when two forms of projectiles are considered, is solved by the introduction of the single type.

(*b*) The high-explosive shrapnel when employed as time shrapnel projects, in addition to the balls, a high-explosive head. This high-explosive head should be effective against the carriages of opposing artillery. Also it should facilitate observation of fire.

(*c*) High-explosive shrapnel has considerable shrapnel effect when bursting on impact, whereas common shrapnel is practically harmless unless striking on hard ground.

It should be understood that the high-explosive shrapnel is a compromise projectile, justified unquestionably by the resulting simplification of ammunition supply. The shell effect of the single-type projectile is slightly inferior to that of the high-explosive shell, and the number of balls contained in its case is fewer than in the common shrapnel.

Chapter V.

CALCULATION OF THE ELEMENTS OF FIRE.

31. General considerations.—Field Artillery Drill Regulations contain sufficient information to enable a commander of a field artillery unit to direct the fire of his unit upon any target assigned to him. This part of the regulations should be studied carefully, as it contains the rules upon which the mastery of the commander over his plant is based. The matériel has been designed for rapid, accurate work; it is supposed that the personnel have been trained properly; it now becomes the duty of the individual in control of this plant to equip himself with the power to use it rapidly and efficiently.

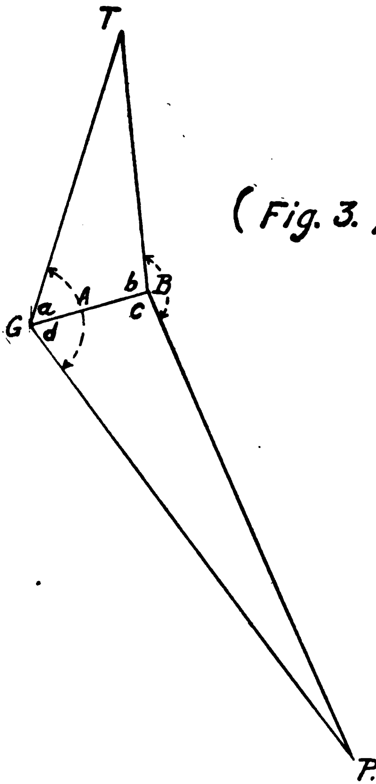
32. Preliminary computation.—For direct laying, few, if any, computations are necessary. The aiming point is the target itself and the deflection set off on the sight compensates for drift and wind. No correction for angle of sight is necessary, due to the fact that the range is set off on the rear sight shank, after which the line of sight is directed upon the target.

When indirect laying is employed it becomes necessary to determine the horizontal angle between the axis of each piece, properly directed upon its target, and the line joining each panoramic sight and the selected aiming point. The angle of site from gun to target must be determined and the guns must be located in such manner that their fire will clear the mask and otherwise conform to the nature of the particular problem. Firing data are determined at the observing station and there transformed for use at the guns.

33. Deflection of any piece.—The solution of this problem has for its aim the determination of the horizontal angle in mils between the line of sight and the axis of the piece, so that the fire of this piece may be toward and in the direction of the assigned target. In

the general problem any position may be chosen for the gun, aiming point, target, and observing station. The angular quantities entering the solution are obtained at the observing station by means of the battery commander's telescope, the battery commander's ruler, or by handbreadths; linear elements entering the solution are measured or estimated. In the usual case the deflection of the right piece is determined and a deflection difference calculated, which, if applied in arithmetrical progression to the deflection of the right piece, gives the proper deflection for the piece considered.

34. Deflection of the right piece.—In figure 3, T is the position of the target; G the position of the gun; B and P the positions of the B. C. telescope and aiming point, respectively. T represents also the angle BTG; P the angle BPG; B the angle PBT; A the angle PGT, which is the sum of the angles *a* and *d*.



(Fig. 3.)

Based upon the fact that the sum of the interior angles of a triangle equals 180° and that the sum of the angles about a point equals 360°, the following equations may be written:

$$a+b+\mathrm{T}=180°$$
$$d+c+\mathrm{P}=180°$$

by addition

$$a+d+b+c+\mathrm{P}+\mathrm{T}=360°$$

also

$$\mathrm{B}+b+c=360°$$

by subtraction

$$a+d-\mathrm{B}+\mathrm{P}+\mathrm{T}=0$$

hence

$$a+d=\mathrm{A}=\mathrm{B}-\mathrm{P}-\mathrm{T}=\mathrm{B}+(-\mathrm{P})-\mathrm{T}$$

in which A is the deflection required, B is the measured deflection at the B. C. station from aiming point to target; it being impossible to measure T and P, these angles must be computed by trigonometrical methods or by approximate methods to be explained. From trigonometry

$$\frac{\mathrm{Sin\ P}}{\mathrm{BG}}=\frac{\mathrm{Sin}\ c}{\mathrm{PG}}$$

and

$$\frac{\mathrm{Sin\ T}}{\mathrm{BG}}=\frac{\mathrm{Sin}\ b}{\mathrm{PG}}$$

TG is the range from gun to target.

PG is the distance from gun to aiming point, and BG is the distance from gun to B. C. station, which distances must be accurately known, if the deflection desired is to be accurately determined.

Taking another case and retaining the nomenclature in figure 3, refer to figure 4, in which—

$$a+b+\mathrm{T}=180°$$
$$d+c+\mathrm{P}=180°$$

hence

$$a+b=180°-\mathrm{T}$$
$$d+c=180°-\mathrm{P}$$

but

$$\mathrm{B}+b-c=360°$$
$$\mathrm{A}+d-a=360°$$

therefore

$$\mathrm{B}+b-c=\mathrm{A}+d-a$$

or

$$B+(a+b)=A+(d+c)$$

substituting

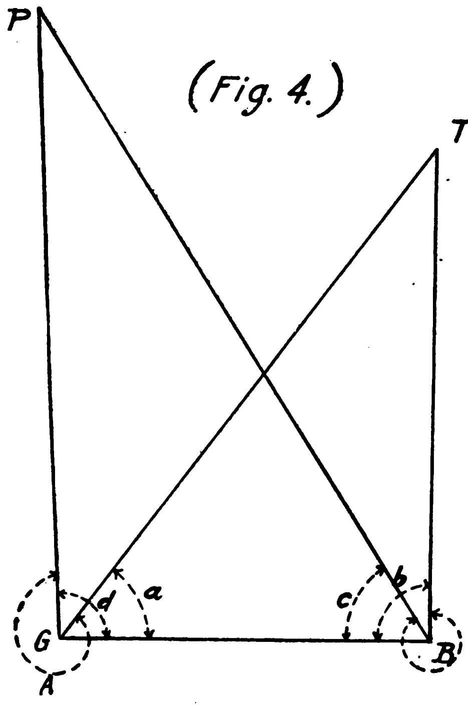
$$B+180-T=A+180-P$$

solving

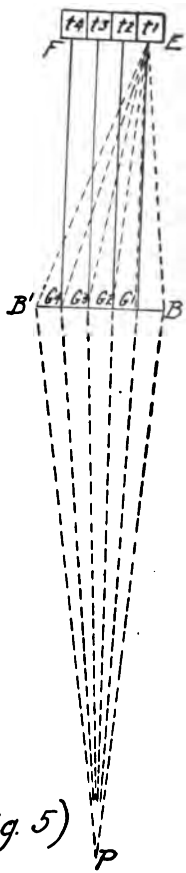
$$A=B+(+P)-T$$

from which it is seen that the required deflection of the right piece can always be expressed in terms of B, P, and T, and that P is positive when the aiming point is in front of the line BG, and negative when in rear.

In theory the deflection of any piece may be determined as shown above for the right piece. The measured angle B is constant, but P and T vary with BG, which is the distance from the observing station to the gun considered. In practice the application of accurate trigonometric methods is not warranted, as exceptionally close approximations may be made quickly. The manner of making such approximations will be considered under the theory of parallaxes.



(Fig. 4.)



(Fig. 5)

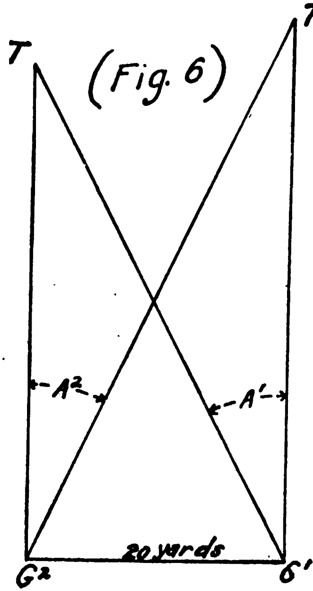
35. Deflection differences.—If the guns of a battery at G_1 G_4 in figure 5 be accurately laid for converging fire upon a target t_1 and the panoramic sights be then turned upon a common aiming point P, the sight readings will be found to vary from G_1 to G_4 by differences which are for all practical purposes equal from gun to gun throughout the battery. It is evident from the figure that if the azimuth or deflection for the right piece be known, that for the second piece may be obtained by applying the common difference to the sight reading of the right piece. In a similar manner the sight settings for the third and fourth pieces may be found. This common difference is called the *convergence difference.*

If now it be desired to lay the guns so as to distribute the fire over the entire front of the target EF, t_1 being the particular target of the right piece and t_4 that of the left piece, it will be seen that the readings of the sight at G_2 must be increased by the angle $t_1G_2t_2$, expressed in mils; that of G_3 must be increased by twice as much, and that of G_4 by three times as much. There is consequently a second common difference which, added to the sight settings for converging fire, will give the correct settings for distributed fire. This common difference is called the *distribution difference.*

The algebraic sum of the two differences is called the *deflection difference.* In the case of converging fire, the distribution difference is zero and the deflection difference is the same as the convergence difference; in the case of parallel fire, the distribution difference added is equal to the parallax of the target, and the deflection difference therefore becomes equal to the parallax of the aiming point.

To lay the guns upon their appropriate targets in indirect laying, it is then necessary to determine, first, the deflection of the right piece and, second, the deflection difference.

36. Parallax of a point.—In practice the parallax of a point is taken to be the angle, expressed in mils, subtended at the assumed point by one platoon front (20 yards) at the position of the observer.



Thus if G_1, G_2, figure 6, represents a platoon front, the parallax of T is the angle G_1TG_2 in mils. The parallax of P is the angle G_1PG_2. Applying the rule $A=B+(P-T)$ to this case A becomes A_2 and B becomes A_1, hence $A_2-A_1=P-T$, in which P is positive when the aiming point is in front of the line of guns and negative when in rear. It should be noted that in this case A_1 is the deflection of the right piece and A_2 is the deflection of the second piece. A_2-A_1 is therefore the convergence difference, usually represented by CD.

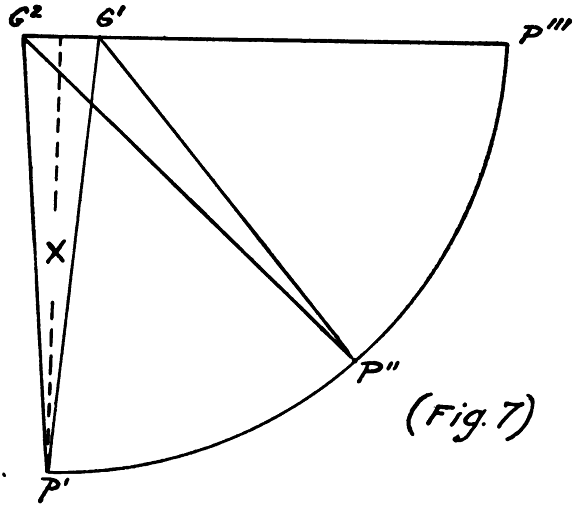
Therefore to determine the convergence difference, knowing the parallax of the aiming point and that of the target: *Subtract algebraically the parallax of the target from the parallax of the aiming point, giving to the latter the negative sign when the aiming point is in rear of the gun; the result, positive or negative, is the convergence difference.*

Without entering further into the subject it is believed that the reasons for the rules set forth in the Drill Regulations for the determination of the deflection difference will be apparent.

The rules give a ready means of obtaining the deflection difference when the parallaxes of the target and aiming points are known. To determine these parallaxes the range and the distance to aiming point should be determined.

96609°—11——3

37. Application of rules for determining deflection differences.—The parallax of a point directly in rear of a firing unit at normal intervals is 20 divided by range to point in thousands of yards; if, however, the point is taken on the extension of the line of guns, the parallax becomes zero. In figure 7, G_1G_2 is one platoon front and P′, P″, P‴ are different positions of the aiming point.



(Fig. 7)

It will be seen that the angle G_2PG_1 has its maximum value when the aiming point is directly in rear and that the angle in question diminishes in value until P coincides with P‴, where the parallax is zero. When the line from aiming point to any piece is considerably oblique to the line of guns, such obliquity must be considered in arriving at the proper value for the parallax. By means of the parallax table on the B. C. ruler can be found the parallax

of a target or aiming point situated in any direction with reference to the front of the firing unit. The parallax of P above varies from $\frac{20}{1000}\text{X}$ to zero, hence for distant aiming points no great error will be made in neglecting corrections for obliquity.

88. Application of rule for determining deflection of right piece.—If the observing station, B, figure 5, on the right flank of the firing unit, is but one platoon front away, the deflection of the right piece is obtained by applying the convergence difference to the measured deflection at the observing station. If the observing station is n platoon fronts away, n times the convergence difference must be applied to the measured deflection PBt_1 or

$$PG_1t_1 = PBt_1 + n(CD)$$

The essential signs of both n and CD must be considered, n being positive when the B. C. telescope is to the right of the firing unit and negative when it is to the left.

As n increases it is necessary to determine with greater accuracy the value of the convergence difference.

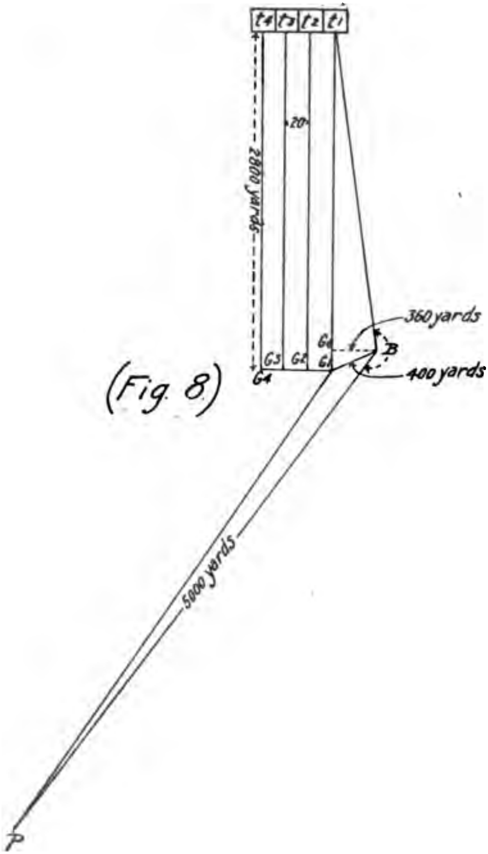
If the observation station is not exactly on the prolongation of the line of guns, but is near it, the deflections may be determined practically as explained in the case when the B. C. telescope is on the prolongation of the line of guns, except that instead of measuring the distance from observing station to right piece to determine n, the distance from observing station to the line of fire G_1t_1 is measured on a line parallel to the front of the firing unit.

The solution of a problem will illustrate the application of the parallax method.

Measured deflection:

B=4,165
P=—2.2 (obliquity considered corresponding to measured deflection).
$n=+18$
$T = \frac{20}{2.8} = 7$

Deflection of right piece $= PG_1t_1 = 4{,}165 + 18\,(-2.2-7)$
$= 4{,}165 - 166$
$= 3{,}999$



t4
t3
t2
t1
20
2800 yards
360 yards
G4
G3
G2
G1
B
400 yards
5000 yards
P

(Fig. 8)

For converging fire

$$DD=CD=-10$$

hence $PG_2t_1=3{,}989$

$PG_3t_1=3{,}979$

$PG_4t_1=3{,}969$

For distributed fire

$$\text{Deflection difference}=-2.2-7+\frac{F}{X}$$

in which F is front of targets in mils and X equals number of guns to which target is assigned.

Suppose $F=150$ mils

$X=4$

then $\frac{F}{X}=37$

$$DD=-2.2-7+37=+28$$

For parallel fire:

In order to cause the pieces to be directed on the opposing parts of their targets, deflection difference=parallax of aiming point= -2.2, since,

$$DD=-2.2-7+\frac{F}{X}$$

$$\frac{F}{X}=\frac{80}{2.8}\div 4=7$$

$$\therefore\ DD=-2$$

in which F is front of target in mils and X equals number of guns firing.

$PG_2t_2=3{,}997$

$PG_3t_3=3{,}995$

$PG_4t_4=3{,}993$

Chapter VI.

RAPID CALCULATION OF THE ELEMENTS OF THE TRAJECTORY.

39. General considerations.—As is the case with other professions the practice of which is based upon the intelligent application of natural laws, field artillery has its empirical rules. Such rules are more or less closely in accord with mathematical facts, the departure from such facts being in the form of close approximations easily remembered and quickly applied. All the elements of the trajectory in air may be computed with any desired degree of accuracy, but such computations can not be made quickly even under the most favorable conditions. Due to certain interesting relations between various elements of the trajectory, approximations sufficiently close for practical purposes may be carried in the head without the necessity of using range tables or logarithms.

40. Units of measure.—The yard is the usual unit of distance. The unit angle is the mil.

The true mil is a thousandth part of a radian, or practically $\frac{1}{1570}$ part of a right angle; the mil adopted is $\frac{1}{1600}$ part of a right angle and is smaller than the true mil by approximately 4 seconds of arc.

Based upon the assumption that 6,400 mils equals 360 degrees, or 21,600 minutes, degrees may be converted into mils by first reducing the degrees to minutes and then multiplying by 0.3.

Example: The angle of departure 5° 12′, corresponding to a horizontal range of 3,000 yards, equals 312 minutes, or 93.6 mils. Actually, the angle in mils should be 92.4, which does not vary greatly from that given by the approximate method.

The converse of the above rule is true, and mils may be transformed into minutes by dividing by 0.3.

41. Angles of departure.—Denote by K any tabular range in thousands of yards. If ϕ is the angle of departure in mils corresponding to a range less by a hundred yards, then ϕ_1 corresponding to the range K will be equal to $\phi + K + 1.4$ in mils, or, *the increment of the angle of departure corresponding to an increase in range of 100 yards is equal to K + 1.4 mils.*

Example: The angle of departure for range 3,000 is 92.4 mils. For 3,100 yards K = 3.1, hence increment ϕ equals 3.1 + 1.4 or 4.5 mils, which added to 92.4 gives 96.9 mils, differing by only $\frac{1}{10}$ of a mil from the tabular angle of departure.

Example: ϕ for 4,800 yards is 186 mils; K for 4,900 equals 4.9; ϕ for 4,900 yards is 192.3 mils.

The above rule may be written in a more general form, as follows: *The increment of the angle of departure corresponding to an increase in range of n100 yards is equal to* $n(K_1 + 1.4)$ *mils.* K_1 is the average value in thousands of yards of the two ranges considered.

Example: The angle of departure for range 1,000 is 21 mils; for 6,500 yards $K_1 = \frac{6.5+1}{2} = 3.75$; 55×3.75 equals 206.25; 55×1.4 equals 77; ϕ for 6,500 equals 206 + 77 + 21 = 304 mils (tabular value is 305.8).

The above rules assume that the angle of departure corresponding to some range has been committed to memory. This is not necessary, as the angle of departure corresponding to any range may be computed by means of the following formula:

$$\phi \text{ in mils} = 5K(K+3)$$

Example: Let it be required to compute the angle of departure corresponding to a range of 4,000 yards. K = 4; 20(4 + 3) = 140 mils.

42. Range for any assumed angle of departure.—Take the equation

$$\phi = 5K(K+3)$$
$$\phi = 5K^2 + 15K$$

Solve for K,

$$K^2 + 3K = \frac{\phi}{5}$$

Completing square

$$K^2 + 3K + \tfrac{9}{4} = \frac{\phi}{5} + \tfrac{9}{4}$$

Extracting root,

$$K + \tfrac{3}{2} = \sqrt{\frac{\phi}{5} + \tfrac{9}{4}}$$

Transposing and simplifying

$$K=\sqrt{\frac{\phi+11}{5}}-1.5$$

Example: Given $\phi=114$ mils; required the corresponding range.

$$K=\sqrt{\frac{114+11}{5}}-1.5=3.5$$

The range is therefore 3,500 yards.
Suppose $\phi=306$ mils.

$$K=\sqrt{\frac{317}{5}}-1.5=6.5 \text{ (very closely)},$$

or the range is 6,500 yards.

43. Angle of fall.—The angle of fall, in mils, is approximately one and a half times the angle of departure. At a range of 6,500 yards the angle of fall computed by the approximate method would be about 10 mils too small; at short and mid ranges the variation is negligible.

It will be seen that the formulas for ascertaining the angle of departure corresponding to an assumed range apply to angles of fall by the introduction of the factor $\frac{3}{2}$ in the second terms.

For instance,

$$\phi=5K(K+3)$$

becomes

$$\omega=7.5K(K+3).$$

44. Time of flight.—An approximate equation for obtaining the value of the time of flight may be written as follows:

$$T=\left(\frac{\phi+K}{10}-\frac{K^2}{5}\right)=\frac{\phi}{10}+\left(\frac{K}{10}-\frac{K^2}{5}\right)=\frac{\phi}{10}+\frac{K}{5}\left(\frac{1}{2}-K\right)$$

in which ϕ is the angle of departure in mils.

From an examination of this equation it will be seen that for short ranges a close approximation to the time of flight will result from taking one-tenth of the corresponding angle of departure in mils.

Substituting in the equation under consideration the value of ϕ in terms of the range, or, $\phi=5K(K+3)$, we find:

$T=\frac{K}{10}(3K+16)$, a very simple formula and dependent upon the range alone.

Thus for	Tabular values.
1,000 yards, T=1.9	2.07
2,000 yards, T=4.4	4.75
3,000 yards, T=7.5	7.83
4,000 yards, T=11.20	11.25
5,000 yards, T=15.5	15.12
6,000 yards, T=20.4	19.36

The formula is sufficiently accurate at all ranges, and particularly so from 2,500 to 5,000 yards.

45. Maximum ordinate.—The maximum ordinate is equal in feet approximately to four times the square of the time of flight in seconds. It is at a distance from the origin equal to approximately three-fifths of the range, or the range to the foot of any maximum ordinate is equal to that resulting from one-half the angle of departure.

Example: For a range of 4,200 yards the time of flight is 11.99 (say 12) seconds; $4\times12^2=576$ feet (tabular value 610); the distance to maximum ordinate is three-fifths of 4,200, or 2,520 yards; the angle of departure for 4,200 yards is 151.4 mils, one-half of which—75.7 mils—corresponds to a range of 2,600 yards.

46. Firing over a mask.—In the selection of concealed positions it is important to so locate the guns that the trajectories may clear the mask. For the proper solution of the problem a knowledge of the height of the trajectory above the line of sight is necessary.

For cases in which the height of the mask in yards is known, Gen. Percin, of the French Artillery, has deduced a simple rule of approximation. For the actual trajectory he has substituted a parabola passing through the origin and the point of fall, whose ordinates at all points of the range are inferior to the ordinates of the real trajectory. The equation of the Percin parabola is

$$4y=x\,(R-x)$$

in which

y is the ordinate in yards corresponding to any point x.

x is in the general sense any abscissa; in the special sense it is the distance from gun to mask in hundreds of yards.

R is the entire range from gun to object in hundreds of yard·

Solving for x,

$$x=\frac{4y}{(R-x)}$$

from which it is seen that, under the rule, a projectile will clear the mask when fired at a distance from the mask equal to four times the height of the mask in yards, divided by the range from mask to object in hundreds of yards.

Example: The range from mask to target is 4,000 yards; height of mask 20 yards.

$$4y=80$$
$$(R-x)=40$$
$$x=200 \text{ yards.}$$

At 200 yards the angle of site of the mask is 100 mils; the angle of departure corresponding to range of 4,200 yards is 151.4 mils, hence it will be seen that the rule gives a large factor of safety for horizontal ranges. Even for an angle of site of target as low as 250 the projectiles in this case would clear the mask.

Let S=angle of site of mask

then $S=\frac{\frac{y}{x}}{10}=10\frac{y}{x}$

$$\frac{y}{x}=\frac{S}{10}$$

from the equation of the parabola above

$$\frac{y}{x}=\frac{1}{4}\,(R-x)$$

or

$$\frac{S}{10}=\frac{1}{4}\,(R-x)$$

or

$$S=2.5\,(R-x)$$

..om which it is seen that the trajectory will clear if the guns are placed at a distance from the mask such that the angle of site of the

mask from the gun, in mils, is equal to or less than two and one-half times the distance from mask to target in hundreds of yards.

In the formula just considered the distance from mask to target has been considered, no allowance having been made for approach of target. If it is desired to limit the dead space to a definite distance this distance in hundreds of yards should be chosen, instead of the range from mask to target. Gen. Tariel, also of the French Army, has written a formula in which he considers the necessity for observation of the ground in front of the target. In his formula

$$S=30\ (K-1)$$

Example: Let the range be 2,000 yards, then S=30 mils=minimum angle of site of mask from position of guns; 30 mils corresponds to the angle of departure for a range of 1,350 yards, hence there will be a margin of fire of 650 yards.

In the discussion contained in this paragraph it has been assumed that the guns and target are on the same horizontal plane. If such is not the case the angle of site of the target should be considered.

Percin's formula becomes

$$S=2.5\ (R-x)+(\varepsilon-300)$$

Tariel's formula becomes

$$S=30\ (K-1)+(\varepsilon-300)$$

47. Height of trajectory at any distance from origin.—For flat trajectories, or in other words whenever the principle of the rigidity of the trajectory applies, the relation between an abscissa and its corresponding ordinate may be written as follows:

$y=x\ (\phi_k-\phi_x)$
ϕ_k is the angle in mils corresponding to the entire range.
ϕ_x is the angle in mils corresponding to the abscissa x.
y is height of ordinate in yards.
x is the abscissa in thousands of yards.

From the equation $\phi=5K(K+3)$

We may write $\phi_k=5K(K+3)$

$$\phi_x=5x(x+3)$$

Substituting these values on the above equation,

$$y=x[5K(K+3)-5x(x+3)]$$

we have an equation by which the trajectory corresponding to any range may be constructed. The time of flight may be found from

$$T=\frac{K}{10}(3K+16)$$

For the angle of fall,

$$\omega=7.5K(K+3)$$

The student should bear in mind that the above formulas are closely approximate only; that accuracy resulting from the application of correct ballistic formulas has been somewhat sacrificed in the desire for simplicity and rapidity of computation. For practical purposes the field artilleryman requires no more accurate methods than the ones laid down in this chapter; as a matter of interest, however, he is referred to the well-known texts dealing with the subject of exterior ballistics.

The approximate methods set forth in this chapter may be applied to any gun, with obvious changes in the constants. For instance, referring to the range table for 2.95-inch mountain gun (Vickers-Maxim), 12½-pound projectile, muzzle velocity 920 feet per second, it will be seen that

$$\text{(angle of elevation)}=8K(K+6)$$

$$\text{(time of flight)}\quad=\frac{4K}{10}(K+6)$$

CHAPTER VII.

ACCURACY OF FIRE AND CAUSES AFFECTING IT.

48. Causes affecting accuracy.—There are two principal causes affecting the accuracy of field gun fire:

First. Errors committed by the personnel charged with the various incidents of fire.

Second. Irregularities in the matériel supplied by the Ordnance Department.

49. Errors committed by the personnel.—In order that the projectile from any gun may hit the target the gun must be fired at a certain angle of departure, depending upon the range and upon the relative level of the gun and the target, and must be given such direction to the right or left of the target as to neutralize the deviation of the shot from the plane of fire due to the drift and wind. In shrapnel fire the fuse must be set to function at the proper height and at the proper distance in front of the target.

Whether the laying be direct or indirect, the accuracy of fire depends upon the correct manipulation of the instruments for laying and fuse setting. The battery commander is responsible for the correct adjustment of his instruments before firing; and during target practice or combat the platoon commanders and chiefs of sections supervise the service of their guns, the latter watching particularly to see that sights, quadrants, and fuses are properly set. It must be understood that before the broader moves in the artillery game may be played with confidence, and before the commander can utilize the wonderful flexibility of his fire, he must train his organization in the manipulation of the few instruments of precision with which the guns are equipped. When the machine is perfect within itself, its commander will realize his reward in the possession of a fighting unit of enormous power, susceptible of accurate and flexible direction.

Based upon the analysis of many rounds of the 3-inch shrapnel ammunition, fired at proving grounds, we may safely conclude that where the gun has been accurately laid in elevation and for direction

range errors will be negligibly small. This refers particularly to bursts upon impact with the ground and only in a general way to air bursts, which latter action does not depend solely upon the proper laying and fuse setting.

50. Irregularities in matériel.—The gun and ammunition are subject to the usual errors found in manufactured products. Compared with commercial articles the accuracy and regularity of their construction is remarkably high, due principally to the well-drawn specifications furnished by the Government and to the careful inspection of all material and the manner of converting it into war supplies.

Any error existing in a new field gun is negligible. A gun which has had a projectile burst in its bore may be deformed or scarred; or it may pass its accuracy life after having been fired many rounds. A premature burst is a very rare occurrence, and, in so far as the gun itself is involved, should not be viewed with concern. The elastic strength of our 3-inch field gun is in excess of the force of an explosion of any one of its service projectiles. The accuracy life of a field gun is a long one, and perfectly acceptable results should be obtained with a gun from which 2,000 rounds have been fired.

In the projectiles themselves will be found the chief sources of error not attributable to errors in laying and fuse setting. Different projectiles of the same type may not weigh the same. In fact, the Ordnance Department, for reasons of economy of manufacture, finds it necessary to tolerate a variation of 1 per cent from the prescribed weight of the service 3-inch 15-pound shrapnel.

The center of gravity of a projectile may lie slightly off its longer axis. This would affect its accuracy. Roughness of the projectile would increase the resistance of the air to its motion and any error in the dimensions of its rotating band would affect its muzzle velocity.

The muzzle velocity is a variable due to well-known causes. The powder of different charges may be of different temperatures; its burning may not proceed identically each time; again, the varying weights of the projectiles and variations in the dimensions or deformation of the rotating band, all tend to vary the actual muzzle velocity from that chosen as the standard. In practice the errors due to all of the above causes, acting simultaneously, are very small. No serious error will be committed in assuming the behavior of the mean of many shots to be that of any one of them.

The shrapnel, set for time burst, is subject to another set of errors due to irregularities in manufacture and the various conditions of its

service. The handbook contains a description of the service combination fuse. The time element of this fuse regulates the point of burst of the shrapnel for any given trajectory.[1] The time trains are formed of compressed meal powder and burn with a great degree of regularity. Due to atmospheric conditions during the pressing of the trains and due to small variations in moisture content of the powder from day to day, the time of burning to any fuse setting is found to be slightly variable. The concussion primer does not act precisely the same at all times and the powder pellets, whose function it is to transmit the flame from primer to upper train and from upper train to lower train, give small variations which do not seem to yield entirely to refinements in the fuse; these irregularities, together with the usual range errors (variations in the elements of the trajectory) are responsible for what is known as the dispersion of points of burst. The dispersion of service fuses is carefully determined at several ranges for each lot of 1,000 fuses. For the maximum range of about 6,500 yards the average dispersion in all lots of recent manufacture is about 110 yards. In other words, for the same range and fuse setting the range difference between the shortest and the longest burst is 110 yards.

51. Irregularities in the fuse due to personnel.—For the interest of the student certain facts are quoted from a report of the Field Artillery Board upon the expenditure of 2,000 rounds of the best available shrapnel of domestic manufacture. This shrapnel was fitted with the F. A. 21-second combination fuse, model 1907. The quoted paragraphs will indicate the necessity for a thoroughly trained personnel.

"Throughout this firing, whenever there appeared a burst which seemed erratic, if the mechanism of fire then being used and the tactical conditions permitted, an immediate examination was made of the laying and of all sight, quadrant and fuse setter readings, so that the cause of the irregularity might be determined. If the mechanism of fire was, for example, 'volley fire' with more than one round, at the conclusion of the problem the men were ordered to step back from the guns and a careful examination of the laying and all the different settings was made. By this means it was definitely determined in every case whether the responsibility for the irregu-

[1] The time element shown in the handbook does not differ materially in the high explosive shrapnel—in fact the general type of fuse used in the American Army is similar to that of other armies, except in the method of venting.

larity of burst lay with the fuse or the personnel of the gun detachment. The test comprised the following problems and mechanisms of fire:

"1. Six different battery problems involving indirect laying; target, a hostile battery, the flashes of whose guns were visible over crest concealing battery; ammunition allowance 24 shrapnel, for each battery.

"These problems required careful adjustment and were solved in approximately 15 minutes each. There were no erratic bursts.

"2. Six different battery problems involving direct laying; target, an infantry skirmish line; volley fire sweeping used; ammunition allowance, 38 shrapnel for each battery.

"These problems required rapid work on the part of the gun squad and were solved in as low as six minutes. There were some erratic bursts in this series, which investigation showed were due to faulty laying, the gunner firing into an intermediate crest between the guns and targets.

"3. Six different battery problems involving indirect laying; target, a battery concealed behind crest, searched for by successive volleys; ammunition allowance for each battery, 30 shrapnel.

"The requirements of these problems made the solution necessarily slower than the former problems and 15 minutes was considered a good exhibition. No irregular bursts.

"4. Six different battery problems involving zone fire with indirect laying; target, a battery unlimbering behind crest, with limbers and personnel represented as moving to rear and flanks; ammunition allowance for each battery, 40 shrapnel.

"These problems were solved with the gun squads working with the greatest rapidity possible, a time of as low as four minutes being obtained. No irregular bursts.

"5. Six different battery problems, involving zone fire sweeping, with direct laying; target, a large body of infantry, covering a space of some 200 by 300 yards; ammunition allowance for each battery, 56 shrapnel.

"These problems required great speed and were solved in as short a time as three and one-half minutes.

"In this series were noticed quite a number of irregular bursts. In one battery, very short bursts were found to be due to the chief of platoon giving the range 1,000 yards less than the one announced by the captain.

"In another battery, very high bursts were found to be due to defective laying on the part of the gunner.

"6. Six different battery problems, involving direct laying at a moving target representing cavalry emerging from concealment some 1,200 yards away from the position of the battery and charging the guns. The sleds in each case continued the run until they reached the guns; ammunition allowance for each battery, 28 shrapnel.

"This problem involved the most rapid work possible at the fuse setters, and was solved in as low as 1 minute and 30 seconds from the first to last shot of the series. As the targets were moving with great rapidity, it was practically impossible to determine irregularities in range with reference to the targets, if any existed. The action of the fuse appeared normal.

"7. Two battalion problems involving indirect laying; target, a line of hostile infantry, approximately equal to that of the battalion; ammunition allowance, 42 shrapnel for each battalion.

"This firing was relatively quick for the size of the unit and the method of laying, consuming some 10 minutes, and no erratic bursts were noted.

"8. Two battalion problems, involving indirect laying, with the target representing a hostile battalion, whose position behind a crest is revealed by the flashes of its guns; ammunition allowance, 42 shrapnel for each battalion.

"This firing was relatively quick, also, consuming some 10 minutes in the lowest case, and no irregular bursts were noted.

"9. Two battalion problems, involving indirect laying, against a hostile battery, the three batteries of the battalion being separated; ammunition allowance, 62 rounds of shrapnel for each battalion.

"These problems were relatively slow, the quickest consuming some 20 minutes. Some irregularity of burst was noticed. One shot, which burst a considerable distance beyond the target, was judged a ricochet, while in case of one which burst short and high it was impossible to determine any external error. This erratic burst was ascribed to some defect in the fuse.

"10. One regimental problem, involving indirect laying, target a line of infantry about equal in length to that of the regiment; ammunition allowance, 68 shrapnel.

"The firing was deliberate, and no erratic bursts were noted.

"11. One regimental problem, with the battalions separated, involving indirect laying, against a hostile battalion of field artillery; ammunition allowance, 84 shrapnel.

"The firing was deliberate. Eight quite high bursts were noted in the final regimental volley, which were ascribed to the respec-

tive No. 1s of pieces which had not been used in the adjustment and who did not carefully center their bubbles in the final volley.

"12.[1] One regimental problem, indirect laying; ammunition allowance 140 shrapnel. The target in this case was a line of kneeling figures along the military crest of a ridge, with gentle slope, near the target of perhaps one on twenty. At distances of 100, 200, and 300 yards from the target were placed standing figures, representing lines of advancing infantry. The fire was adjusted on the target and all figures marked, so as to eliminate hits due to adjustment. Fire was then resumed, and subsequent inspection of the target showed no hits on either the 200 or 300 yard lines and only three hits on the 100-yard line. The target was riddled. This was a very important test, and shows that * * * our infantry can advance to within remarkably short distances of the enemy without danger from the supporting artillery.

"13. Two battalion problems; horse artillery firing upon defeated infantry; direct laying; ammunition allowance, 42 shrapnel for each battalion.

"These problems were solved very rapidly—inside of three minutes each—and no erratic bursts were noted."

It will be seen that among the irregular bursts noted all but one were due to the personnel.

52. Accuracy and probability of fire.—As a result of inaccuracies, due to faulty matériel and to errors committed by the personnel, two successive rounds rarely, if ever, fall in exactly the same place. In practice this means that the trajectories of a number of projectiles fired under as nearly as possible the same conditions do not coincide, but form a cone about the mean trajectory as an axis. This cone is called the sheaf of fire, the ground section of which is an ellipse, with the longer axis in the direction of the range. In determining the accuracy of a gun at any given range and under any special conditions a number of shots are fired under the given conditions. The firing is done in such manner as to make the circumstances governing all rounds as nearly alike as possible, and the point of fall of each shot is plotted, usually with reference to the assumed origin. The coordinates x and y of each shot mark are measured with respect to two rectangular axes X and Y, intersecting at the assumed origin. The sum of the abscissas divided by the number of the shots is the mean abscissa, and the sum of the

[1] The results of this firing are given in Chapter IV.

ordinates divided by this number is the mean ordinate. The mean abscissa x_m and the mean ordinate y_m are the coordinates of the center of impact. The actual distance of each shot from the center of impact is the absolute deviation for the shot, and the mean of the absolute deviations is the mean absolute deviation for the group. By comparing the mean absolute deviations of different groups of shots we may arrive at the comparative accuracy of different guns or of the same gun under different conditions of firing.

Example: In a test by the Field Artillery Board the 3-inch field gun was fired for accuracy. The target was horizontal and 1,900 yards from the gun. The coordinates of each shot were measured from a line Y normal to the plane of fire, 1,900 yards from gun, and a line X, parallel to the plane of fire and 5 yards to the left of it.

Number of shot.	Coordinates.		Deviations.	
	Range.	Direction.	Range.	Direction.
	Yards.	*Yards.*	*Yards.*	*Yards.*
1	39	10.0	9	4.3
2	35	17.0	13	11.3
3	22	6.5	26	.8
4	69	3.25	21	2.45
5	44	9.5	4	3.8
6	58	5.5	10	.2
7	34	5.5	14	.2
8	84	3.5	36	2.2
9	32	6.0	16	.3
10	42	7.5	6	1.8
11	25	1.5	23	4.2
12	50	2.5	2	3.2
13	40	3.0	8	2.7
14	62	7.5	14	1.8
15	50	5.0	2	.7
16	24	6.0	24	.3
17	28	5.0	20	.7
18	70	3.75	22	1.95
19	57	5.0	9	.7
20	45	.5	3	5.2
21	55	....	7	....
22	67	....	19	....
23	60	....	12	....
24	60	....	12	....
	24)1,152	20)114	24)332	20)48.8
	48	5.7	13.8	2.44

The coordinates of the center of impact are: In the direction of the range, 48 yards; normal to range, 5.7 yards. The mean deviations from the center of impact are: In direction of range, 13.8 yards; normal to range, 2.44 yards. The mean absolute deviation=

$$\sqrt{\overline{13.8}^{2}+\overline{2.44}^{2}}=\sqrt{196.39}=14 \text{ yards, approximately.}$$

53. Total rectangle.—For convenience, it is usual to express the elliptical area or ground section of the sheaf of fire in terms of the enveloping rectangle. An examination of the table above will show that all the shots were contained in a rectangle 62 yards long by 16.5 yards wide. This rectangle is known as the 100 per cent or total rectangle.

54. Probability of fire.—The principal value of the preceding examination into the behavior of the 3-inch gun is to obtain some idea of the number of hits that may be expected when the personnel is performing perfectly. The test from which the above record is taken was supervised carefully and was supposedly free from personal errors. It has been seen that the mean range deviation is 13.8 yards and that the mean direction deviation is 2.44 yards. These mean deviations or mean errors are slightly in excess of the probable errors, due to the fact that large errors are less frequent than small errors. In other words, the great majority of shots in a group are relatively near the center of impact. The probable error is obtained from the mean error by multiplying the latter by 0.846. For the case under consideration the probable error in range equals $13.8 \times .846 = 11.67$ yards; the probable error in direction is $2.44 \times .846 = 2.06$ yards.

55. The 50 per cent rectangle.—In a group of shots one-half will fall over or short of the center of impact by amounts equal to or less than the probable error. As half of these will be short and half over, we may construct the 50 per cent rectangle as follows: At distances equal to the probable range error, draw on each side of the center of impact a line normal to the line joining gun and center of impact; at distances equal to the probable direction error, draw on each side of the center of impact a line parallel to the line joining gun and center of impact; the four lines thus constructed will form the 50 per cent rectangle.

Knowing the range and direction errors and the angle of fall at any range, the 50 per cent rectangle may be constructed for hits on a vertical target.

56. Probable error of 3-inch field gun.—The following table, based upon a test by the Field Artillery Board, contains the probable range and direction errors for the weapon under consideration:

Range.	Probable error in range.	Probable error in direction.
Yards.	*Yards.*	*Yards.*
2,000......	12	2
2,500......	15	2.5
3,000......	15	3.0
3,500......	16	3.5
4,000......	17	4.0

57. Application of probabilities.—The dimensions of the 50 per cent rectangle are taken as the unit of comparison and, based upon the theory of errors, the following table gives the dimensions of rectangles of other percentages in terms of the unit dimensions:

Per cent.	Factor Z/Z_1.	Per cent.	Factor Z/Z_1.	Per cent.	Factor Z/Z_1.	Per cent.	Factor Z/Z_1.	Per cent.	Factor Z/Z_1.
1	0.02	21	0.40	41	0.80	61	1.27	81	1.94
2	.04	22	.41	42	.82	62	1.30	82	1.98
3	.06	23	.43	43	.84	63	1.33	83	2.03
4	.07	24	.45	44	.86	64	1.36	84	2.08
5	.09	25	.47	45	.89	65	1.39	85	2.13
6	.11	26	.49	46	.91	66	1.42	86	2.18
7	.13	27	.51	47	.93	67	1.45	87	2.24
8	.15	28	.53	48	.95	68	1.48	88	2.30
9	.17	29	.55	49	.98	69	1.51	89	2.37
10	.18	30	.57	50	1.00	70	1.54	90	2.44
11	.20	31	.59	51	1.02	71	1.57	91	2.52
12	.22	32	.61	52	1.04	72	1.60	92	2.60
13	.24	33	.63	53	1.07	73	1.64	93	2.69
14	.26	34	.65	54	1.09	74	1.67	94	2.78
15	.28	35	.67	55	1.12	75	1.71	95	2.91
16	.30	36	.70	56	1.14	76	1.74	96	3.04
17	.32	37	.72	57	1.17	77	1.78	97	3.22
18	.34	38	.74	58	1.19	78	1.82	98	3.45
19	.36	39	.76	59	1.22	79	1.86	99	3.82
20	.38	40	.78	60	1.25	80	1.90	100	....

The factor Z/Z_1 above shows the dimensions, in terms of those of the 50 per cent rectangle, of the rectangle whose percentage is given in the column next on its left.

For instance, if the 50 per cent rectangle is 24 yards long and 4 yards wide the 60 per cent rectangle will be $24\times1.25=30$ yards long and $4\times1.25=5$ yards wide; the $82\frac{1}{2}$ per cent rectangle will be 48 yards long and 8 yards wide. The $99\frac{1}{3}$ per cent rectangle is four times as long and four times as wide. Practically this rectangle is the enveloping rectangle.

The use of the above table is illustrated by the following:

Example: In firing with shell, what is the chance of hitting a vertical surface 6 feet high and 12 feet wide at a range of 3,500 yards?

From the table in paragraph 56 it is seen that 50 per cent of the rounds should fall in a rectangle 32 yards long and 7 yards wide. The angle of fall is 1 on 5.8; hence the vertical 50 per cent rectangle will be 5.5 yards high by 7 yards wide.

The width of the target is 4 yards or 0.57 of 7 yards. In the table the factor opposite 0.57 is 30 per cent, hence 30 per cent of the shots will be correct for line.

The height of the target is 2 yards or 0.36 of 5.5. In the table the factor opposite 0.36 is 19 per cent; hence 19 per cent of the shots will be correct for elevation.

The probability that one shot will hit the target is $0.19\times0.30=5.7$ per cent; 100 rounds should give 5.7 hits or approximately 17 rounds per hit.

CHAPTER VIII.

THE SINGLE SHRAPNEL.

58. The purpose.—The attack of personnel would be a very difficult matter without shrapnel. The high explosive effect of percussion shell is restricted to a very small area, whereas the shrapnel, burst properly in air, distributes a large number of projectiles, each one of which is capable of killing a man or horse at reasonable distances from point of burst.

59. The bursting of shrapnel.—The shrapnel case is the vehicle for transfer of the shrapnel balls from gun to bursting point. At this point the powder charge in its base is ignited and the balls are driven out with increased velocity. After the time burst each shrapnel ball pursues its own trajectory depending upon its velocity and initial direction. The projectile has a motion of rotation due to which the balls are thrown away from the trajectory which the shrapnel would have followed had it not burst in air. The paths of all the shrapnel balls taken collectively form a cone called the cone of dispersion. The ground section of this cone is an irregular oval with its longer axis approximately in the plane of fire. The dimensions of this section will vary with the angle of fall, the height of burst, the slope of the ground, and the relation between the linear and rotational velocities at instant of time burst.

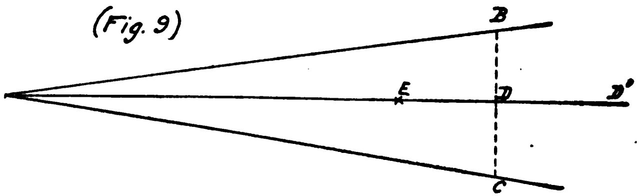
60. Angle of opening.—The angle at the apex of the cone of dispersion may be computed in the following manner: At the instant of time burst the projectile has a remaining velocity in the direction of the range and a rotational velocity about its own longitudinal axis. The balls are given an additional velocity by the base bursting charge. Each ball upon emerging from the shrapnel case has a velocity in the direction of the range equal to the sum of the remaining velocity of the projectile and that velocity imparted to it by the bursting charge; in a direction normal to and away from the trajectory it has velocity due to the projectile's rotation.

In figure 9 assume A as the origin of the cone of dispersion (point of burst). Suppose AE=800 foot-seconds to represent the remaining velocity of the projectile at point of burst, and ED=200 foot-seconds to represent the increase in velocity due to bursting charge. Neglecting the resistance of the air and attraction due to gravity the balls would proceed along the line AD′, if, at the time of burst, the projectile had no motion of rotation.

As the projectile is rotating, let BD=100 foot-seconds, represent its velocity in a direction normal to the trajectory AD′. It will be seen, therefore, that at the end of 1 second the highest ball in the cone of balls will be found at B, having proceeded 1,000 feet in the direction AD′ and 100 feet upward. Such being the case we may write

Tangent BAD=BD/AD
BAD is one-half the angle of opening.

(Fig. 9)



Determination of BD.—Figure 10 is a normal cross section of a projectile making n clockwise revolutions per second. If a particle at B be released, it would leave the circumference along the tangent BD with a linear velocity of $n\times\frac{2\pi r}{12}$ feet per second, hence—

$$BD=\frac{n\pi r}{6} \text{ foot-seconds.}$$

Example: The muzzle velocity of the service 3-inch shrapnel is 1,700 foot-seconds; the bursting charge adds 200 foot-seconds; at the muzzle of the gun the projectile makes one turn in 25 calibers; assume r' (fig. 10) equal to 1 inch.

Solution:

AD=1,700+200=1,900 foot-seconds (fig. 9). The projectile makes one turn in 25 calibers, or 6.25 feet.

1,700÷6.25=272 revolutions per second.

$$BD=\frac{272\times\pi\times1}{6}=142 \text{ foot-seconds.}$$

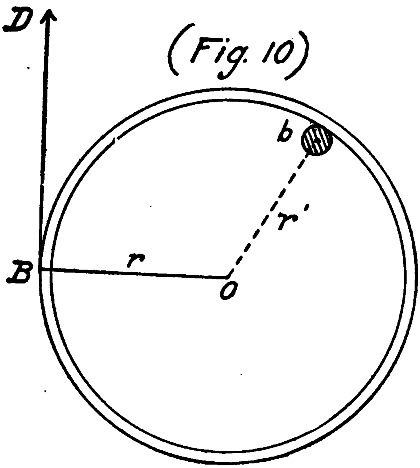
$$\text{Tangent BAD}=\frac{142}{1,900}$$

BAD=4° 16′, which is one-half the angle of opening when the burst is at the muzzle of the gun.

At 1,000 yards the remaining velocity=1,270 foot-seconds. Assume that the rotational velocity of the projectile has fallen off 8 per cent, which is the usual assumption for 1,000 yards, then BD=131 foot-seconds.

$$BAD=\tan^{-1}\frac{131}{1,470}=5°5'$$

The whole angle of opening, BAC, figure 9, is therefore 10° 10′.



Actually the angle of opening is greater than the computed angle. The first layer of balls emerging from the shrapnel case does not get the full benefit of the driving effect of the bursting charge; balls no doubt impact against each other, particularly as those with the greatest velocity emerge last; finally, the expanding gases of the driving charge assist in opening out the cone

of dispersion. Tests made at the Sandy Hook Proving Ground show that at 1,000 yards the angle of opening is very nearly 13°.

As a result of actual firings it has been found that the angle of opening increases as the range increases. The table below is based upon experiment:

Range.	Angle of opening.	Log. tan.
Yards.	° ′	
2,000	14 13	9.40385
2,500	15 00	.42845
3,000	15 42	.44896
3,500	16 18	.46591
4,000	16 52	.48134
4,500	17 26	.49654

61. Height of burst for desired effect.—The theory upon which the proper height of burst of a well-adjusted shrapnel has been based is that for every square yard of a vertical target there should be one ball. It will be seen, therefore, that if the cone of dispersion be intersected by a plane normal to its axis, at such distance from the point of burst that the area of the section in square yards will equal the number of balls in the shrapnel, this distance in yards multiplied by the sine of the angle of fall will give the proper height of burst in yards. Thus, in figure 11:

Let A be point in trajectory OA at which the shrapnel bursts.

θ=one-half angle of opening.

AD=distance to normal section BC.

r=radius of BmCn.

ω=angle of fall.

N=number of balls in shrapnel=250.

Then $r=\text{AD} \tan \theta$

and area of normal section$=\pi r^2$.

$\pi r^2=250$.

$r=8.92$ yards.

As would be expected, the radius of the normal section containing 1 ball per square yard is constant. The distance

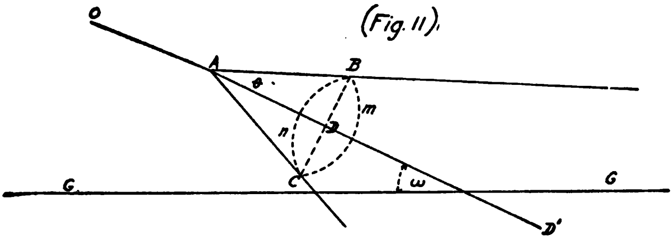
$$\text{AD}=\frac{r}{\tan \theta}=\frac{8.92}{\tan \theta}$$

The table below sets forth information concerning the burst interval for the 3-inch field gun at various ranges. θ is one-half the angle of opening corresponding to the assumed range.

Range.	θ.	1 hit per square yard.		Height of burst—3 mils.	
		Interval AD.	Front covered.	Horizontal interval.	Front covered.
Yards.	° ′	*Yards.*	*Yards.*	*Yards.*	*Yards.*
1,000	6 30	78.3	17.84	118.2	26.9
2,000	7 6	72.2	17 84	85.4	20.6
2,500	7 30	68.4	17 84	73.5	19.2
3,000	7 51	65.3	17.84	66.6	18.2
3,500	8 09	62.3	17.84	60.9	17.4
4,000	8 26	60.2	17.84	56.4	16.7
4,500	8 43	58.2	17.84	51.3	15.7

An examination of the above table will show that between 2,500 and 4,000 yards the height of burst of 3 mils gives approximately the desired density of fire. At ranges less than 2,500 yards the front covered by a burst 3 mils high is greatly increased hence the density of fire is diminished.

(Fig. 11).



62. Effective range of shrapnel balls.—It has been seen that when a shrapnel bursts in air the balls are driven out with an increased velocity of approximately 200 feet per second. The highest shrapnel ball in the cone of dispersion moves along a line inclined

upward to the trajectory of the shrapnel continued, and will have the greatest range of any ball. The actual range of shrapnel balls is ordinarily greater than the effective range. The effective range is the distance from point of burst to a point in the trajectory of the shrapnel ball where its remaining energy is just sufficient to disable a man. In this country it has been assumed that an energy of 58 foot-pounds will serve the purpose, hence the effective range would be measured from the point of burst to the point where the ball has a remaining velocity of v feet per second, such that

$$\frac{Wv^2}{2g}=58$$

$v=\sqrt{\frac{116g}{W}}$ in which g is the acceleration due to gravity and W is the weight of a shrapnel ball, in pounds.

The shrapnel described in the handbook is filled with balls weighing each 167 grains, or 1/42 pound. W therefore equals 1/42, and

$$v=\sqrt{116\times32.2\times42}=396 \text{ foot-seconds.}$$

An examination of the following table will be of interest:

Calculated values of the effective ranges of shrapnel balls.

Number of balls per pound.	Remaining velocity corresponding to energy of—		Effective range of balls beyond points of burst at ranges of approximately—		
	58 foot-pounds.	116 foot-pounds.	1,500 yards.	2,500 yards.	4,500 yards.
	Ft. secs.	*Ft. secs.*	*Yards.*	*Yards.*	*Yards.*
37.74	374	....	425	405	371
37.74	....	532	252	232	198
[1] 41.15	394	....	386	366	336
[1] 41.15	....	554	230	211	177
45.45	410	....	357	337	304
45.45	....	581	208	189	156

[1] Corresponds very nearly with service balls

In practice the effective ranges are found to be somewhat less than those calculated, particularly at long ranges, where the angle of fall is great.

SERVICE TESTS.

The Field Artillery Board during the fall of 1906 conducted certain firings, the principal object of which was to determine the effect produced by a single well-adjusted shrapnel and groups of such projectiles. Firings were conducted at ranges of 1,900, 2,800, 3,500, 3,700, and 4,259 yards against eight board targets, each 40 yards wide and 2 yards high, made of 1-inch lumber. These targets were located 50 yards apart in the direction of the range. Fire was first adjusted on an auxiliary target 100 yards to the flank of the third target, and then shifted to the board target. All incidents of fire were carefully supervised. Service ammunition was used. In drawing conclusions concerning the effect produced only the bullets which perforated the target or which embedded themselves in it were regarded as effective. Bullets which merely dented the target were regarded as ineffective, though the board was of the opinion that many of these would have put a man out of action.

The board concluded as to the effect produced by a single well-adjusted shrapnel:

(a) The front (or width) of target effectively covered at the point of fall is between 18 and 25 yards, being nearer 18 at the long ranges and nearer 25 at the short and midranges.

(b) At ranges up to 3,000 yards, the depth effectively searched is about 200 yards, i. e., about 50 yards in front of the target and about 150 yards in rear of it.

(c) At longer ranges (from 3,500 to 4,500 yards) the depth effectively searched is about 125 yards, i. e., about 25 yards in front of the target and about 100 yards in rear of it.

The above conclusions are well within limits; actually, at a range of 1,900 yards, there were occasional effective hits on seven targets, hence the bullets must have had an effective range of at least 300 yards. At 2,800 yards range there were effective hits on six targets or over 250 yards; at 3,500 the effective hits were spread over at least 200 yards and at 4,259 yards at least 150 yards. If the interval of burst in front of the first target struck be considered and, furthermore, if it be considered that the last target struck was not necessarily at the limit of effect, the actual values of the effective ranges accord closely with the calculated values tabulated above.

63. Density of fire.—The density of fire in the case of a well-adjusted shrapnel is one ball per square yard. In order to attain this density the shrapnel must burst at an interval AD (fig. 11) in front of the target such that

$$AD=\frac{8.92}{\tan\theta}$$

As AD increases, the area of the section BC of the cone of dispersion increases and the density (balls per square yard) decreases.

$$r=AD\tan\theta$$
$$\pi r^2=A=\pi(AD\tan\theta)^2$$

Density in balls per square yard=

$$\frac{250}{\pi(AD\tan\theta)^2}.$$

or the density varies inversely as the square of the interval of burst.

It follows from the above that the number of hits on any target due to any shrapnel burst may be computed.

The following should be known:

Exposed area of target.
Number of balls in shrapnel.
Interval of burst.
Angle of opening.
Angle of fall.

It has been assumed that the trajectory of the projectile continued passes through the target.

Example: What is the density of hits of the service shrapnel at a range of 2,750 yards with interval of burst of 42 yards? of 104 yards?

Example: How many hits may be expected from one round of the service shrapnel, the range being 3,400 yards, the interval of burst 92 yards, on a target 7 yards wide and 6 feet high?

Example: How many hits should be made at 2,300 yards, when firing at a line of skirmishers lying down (each man occupying a front of 0.85 yard), with intervals of burst of 50, 100, 150, and 200 yards?

64. The ground section.—The ground section of the cone of dispersion may be computed, but it is simpler to construct it to scale. The point of burst should be located on cross-section paper;

then, from the proper relations, the angle of opening is determined and laid off in such manner that it will be bisected by the trajectory continued. The ground section is known as the zone of dispersion.

By locating the points in which the limiting bullets of the cone of dispersion pierce the horizontal plane the horizontal zone of dispersion may be constructed. Such drawing would show the influence of the ground upon the depth of effect of a shrapnel. If, for example, it be supposed that the ground at the target has an upward slope of 5°, it is necessary only to construct the points in which the outer bullets pierce the inclined plane. These points limit the new zone of dispersion. It may also be seen from such drawing how the width of the zone of dispersion falls off with small heights of burst. For height of burst greater than the normal the zone of dispersion will be wider. In the latter case the danger of going over the target at short intervals of burst will be greater also.

The curve of the descending branch of the trajectory diminishes the effect, and especially the depth of effect, of shrapnel. The flatter the trajectory the greater the depth of effect.

A study of the ground section of cones of dispersion should be made in connection with the effective ranges of shrapnel balls. It will be found that many balls impacting near the outer limit of a ground section are ineffective due to lack of man-killing energy.

Chapter IX.

THE EFFECT OF A GROUP OF SHRAPNEL.

65. General considerations.—In the preceding chapter the behavior of a single shrapnel, at and subsequent to its burst, has been analyzed. With the knowledge gained during the study of the chapter referred to, the conception of shrapnel fire may be readily extended to include the group. It has been seen that the effect of a single shrapnel depends upon and varies with—

(*a*) The number of balls, N.
(*b*) The angle of opening, $2\,\theta$.
(*c*) The interval of burst.
(*d*) The height of burst.
(*e*) The energy of the balls.
(*f*) The angle of fall, ω.

hence, knowing these quantities for any particular case, the number of hits (effective or noneffective) on a given target, may be computed. Similarly, though with obvious modifications, the effect of a group of shrapnel may be determined.

66. Hits from a group of shrapnel.—Let it be supposed that each shrapnel of the group bursts at the same point in front of the assumed target. If Q men are within the effective zone of dispersion, a certain number m, depending upon the interval of burst, will be killed by the first shot of the group. The number, m, may be expressed as some fraction of Q or $m=Qx$. The men killed by any shot will be a fixed fraction (x) of those left standing after the next preceding shot, but the number of killed per round grows less for each succeeding round.

Thus, in the first round, Qx are killed and $Q-Qx=Q(1-x)$ survive.

In the second round, $Q(1-x)x$ are killed and $Q(1-x)^2$ survive; in the two rounds $Qx-Q(1-x)x$ or $Q(1-(1-x)^2)$ will be killed.

We may write, therefore,

In the n^{th} round $Q(1-x)^{n-1}x$ are killed.

After the n^{th} round $Q(1-x)^n$ survive and during n rounds $Q(1-(1-x)^n)$ have been killed.

It is obvious that

$$Q=Q(1-x)^n+Q(1-(1-x)^n).$$

67. Determination of x.—As stated before, the number of men in any surviving group wholly and effectively covered by the cone of dispersion will be diminished by a definite percentage x at each successive round. It is possible that there may be as many men hit as there are hits per area of each assumed target (men standing, kneeling, or lying down), but it is probable that this number will be smaller, or, in other words, even if the target is covered with the proper density of fire of one hit per unit surface, it is not likely, owing to irregular distribution, that each unit of surface will be struck; the fraction x is, therefore, less than unity.

Gen. Rohne, of the German field artillery, has discussed in his essay on shrapnel fire, the determination of the fraction, x, for any assumed case. He states:

"It remains to be shown how, and why, the probable number of men hit is arrived at. So far as the effect goes, it is evidently immaterial whether one shrapnel with 600 balls or six shrapnel with 100 balls each, burst on the target, supposing always that in each case the angle of opening, the point of burst and the angle of descent are the same, and that in both cases the distribution of the balls within the zone of effect is the same. In a like manner, under the same conditions, it is quite immaterial whether 20 hits result from 1 round, or whether the effect is produced by 20 rounds of which each makes 1 hit. We may thus say that the effect of 1 round which gives n hits is the same as that of n rounds which give 1 hit each."

If then we make m equal 1, $x=\frac{1}{Q}$ and the expression, $Q(1-(1-x)^n)$ becomes, $Q(1-\frac{(Q-1)^n}{Q})$.

Assuming that 30 men stand within the cone of dispersion and that one round gives 20 hits, the effect is the same as if 20 rounds produced 1 hit each. We may therefore write $30(1-(\frac{29}{30})^{20})=14.8$, which is 49.3 per cent of 30, and which corresponds to $x=0.493$ for

$n=1$, thus, $Q(1-(1-x)^n)$ becomes $30(1-0.507)$, or 14.8, instead of 20 for the first round under the assumed conditions.

If it be assumed that 1 round gives 100 hits, $30(1-(\frac{29}{30})^{100})=28.99$ and $x=0.966$ for $n=1$.

That all the men standing in the cone of dispersion are not killed with 1 round is the assumption upon which the method is based; x is always less than unity.

After x is calculated it is of little importance whether any single round of a group under analysis give somewhat more or somewhat less than its proper theoretical percentage of killed. The general result can not be materially affected; if fewer are killed in the first round, more will be killed in the second, and so on.

68. Application of the formula.—Suppose it is desired to determine the number of rounds necessary to put out of action a certain portion, z per cent, of the target. The expressions given in paragraph 66 assume that the first round will hit x per cent of the target, and that after n rounds there remains $(1-x)^n$ per cent of the target not hit. Introducing the condition that z per cent is to be hit

$$(1-x)^n \text{ must equal } 1-z$$

from which $n=\dfrac{\log(1-z)}{\log(1-x)}$

$$\log n=\log.\ \log.(1-z)-\log.\ \log.(1-x).$$

The information contained in Chapter VIII and up to this point in the present chapter is sufficient to enable the student to solve, theoretically, the most important problems in shrapnel fire. It is not the purpose of this volume to consider anything more than the principles underlying the subject of field artillery gunnery and to set forth these principles in such a way that the officer of field artillery in search of further professional knowledge may be directed along the proper lines. A knowledge of the theories upon which practice is based will in many cases be of exceptional interest in the analysis of practice firing.

69. Dispersion of points of burst.—In the discussion which has preceded, it has been assumed that each shrapnel burst at a prescribed distance in front of the target. In practice, due to irregularities of burning of the fuses, the extreme points of burst in a group

fired at a range of 5,000 yards are about 90 yards apart. The 3-mil height at a range of 5,000 yards corresponds to a burst interval of 48 yards, hence when firing a group of shrapnel at this range with mean height of burst of 3 mils there should be no grazes. The nearest burst should occur at 3 yards in front of the target and the most remote at 93 yards in front. At shorter ranges the interval of burst is greater, hence a burst on graze may usually be attributed to errors in laying and fuse setting.

70. The corrector.—The rate of burning of different fuses of the same lot will be found to be fairly uniform, though it will probably vary slightly from that upon which the fuse setter range-ring scale is based.

Before considering the function of the corrector, let it be supposed that a fuse setter, without corrector, is being used and that fire is being conducted with the type lot of fuses, upon the behavior of which the fuse setter range-ring scale is based. If, for instance, the target is on the same horizontal plane as the guns, it will be found that, neglecting the inherent errors of the fuse and assuming normal atmospheric conditions, the shrapnel bursts will be seen in the horizontal plane through the gun; in other words, no matter what the range may be, the fuse will act at the end of that range under the conditions assumed. If the target and gun are not on the same level, and the gun is given an angle of site elevation in addition to the elevation for range, the shrapnel burst will occur in a plane containing the gun and target and perpendicular to the plane of fire; this would follow from a consideration of the theory of the rigidity of the trajectory. Due to fuse errors the bursts, even with the type lot, will not occur precisely in the plane in question, but above and below it in equal numbers.

With other lots of fuses, the majority of bursts, due to a probable variation in rate of burning from the type lot, will occur below or above the plane, depending upon whether the time of burning is too long or too short as compared with the type lot.

The fuse setter was so constructed that corrector 27 would put the bursts in the plane for the type lot of fuses under normal conditions. As each division of the corrector graduations corresponds to a change in the height of burst of the shrapnel equal to one one-thousandth of the range—that is, to 1 mil—it will be seen that the division 30 corresponds to the normal height of burst (3 mils) for fire for effect, if all conditions are normal.

In case the fuses of any lot burn longer than those of the type lot, corrector 27 would not correspond to a burst in the plane through gun and target. The corrector would have to be increased by a number of points equal to the number of mils beneath the plane at which the shrapnel were bursting. If, for instance, the sense of the bursts was 4 mils below, the corrector should be raised to 31 for bursts in the plane and to 32 for the prescribed 1 mil height of burst for fire for adjustment.

Having determined the corrector corresponding to bursts in the plane through gun and target and perpendicular to the plane of fire, as long as atmospheric conditions are normal no further manipulation is necessary except the proper increase for firing for effect, no matter what the range may be.

If, however, atmospheric conditions are not normal, an alteration in the corrector setting will be necessary. The corrector will perhaps vary at different ranges; usually, however, this variation for any probable set of conditions will be very small. Hence it may be stated as a practical working rule that the corrector for one range is good for all.

This rule works satisfactorily for the changes of range used in bracketing, and also generally for greater changes of range in shifting to a new target, although in the latter case a slight readjustment of the corrector may be required.

Chapter X.

RANGING.

71. General considerations.—Ranging is the most difficult as well as the most important part of the adjustment of fire. Skillful ranging at difficult targets requires a great deal of practice in observing the bursts of projectiles.

From the nature of its service, field artillery can not have the stationary appliances of the coast artillery for determining ranges accurately and for making allowances for all conditions of wind, barometer, etc. Furthermore, the shrapnel is its principal projectile and the hitting of a bull's eye is not to be sought.

72. Methods of procedure.—For the field artillery the process of ranging is one of trial shots and the method of procedure for a battery is as follows:

The captain first observes the target and estimates the distance of it from his guns. This estimate may be made with the eye or by the aid of a portable range finder. He then fires at the estimated range and observes whether the projectiles burst short of or beyond the target.

Supposing the bursts to have been short of the target, he next fires a round with increased range, the amount of increase being such as will probably include the sum total of all of the range errors of the gun and ammunition, and of the personnel, including the error that has been made in estimation of the distance to the target.

If this second round is over, a bracket is said to be established; any other trial ranges which he will need to use will be included within the limits of this bracket.

The most logical range for him to use for his third trial is the one midway between the first two, since, whether the third round be short or over, he will have eliminated the ranges in one-half of the bracket from the necessity for further trial.

He continues to halve the bracket last obtained until he has narrowed it down to the needs of the case, but he should never try to get a bracket smaller than the error of his guns.

Having obtained the desired bracket, he then verifies it by firing a sufficient number of rounds at the short and long limits. A single round is never to be trusted for deciding a short or an over which is near the target, since that one round may be an abnormal one, and the waste of ammunition which would result from firing for effect with the erroneous data thus obtained will, in the end, more than equal the expenditure required to verify the bracket. Furthermore, the time lost in firing at an erroneous range before the error is discovered can not be replaced.

A battery salvo is generally sufficient to verify each limit of the bracket. If, during the bracketing process, any of the rounds be observed to produce effect upon the target, the captain may abandon his bracketing process for the time being and fire additional rounds at the same range. If these rounds do not indicate that the range has been found, he proceeds with the bracketing.

The amount of increase of the range for the second trial round is laid down in Drill Regulations as 400 yards. This has been fixed upon as the result of much experience, as the amount necessary to cover all probable range errors. It is also a number which is readily subdivided several times without giving a quotient which is not an even division on the scales.

73. Exceptions to the rule.—The drill book purposely allows exceptions from this rule to fit special cases; but the beginner is prone to apply the exception far too frequently, thinking that he can tell something about the amount that his first round is over or short.

With air bursts which obscure the target or against which the target is silhouetted, it is impossible for an observer near the guns to form an estimate of *how much* the point of burst is short of or beyond the target.

With percussion bursts it is equally impossible, except when the burst is very near the target or when the observer is specially favored by conditions.

With percussion projectiles the distance of the point of burst from the target is largely influenced by the contour of the ground.

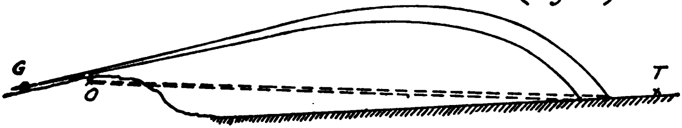
Let us suppose that the observer is on high ground and that the target is on perfectly level ground below him (fig. 12).

This would be a special case in which the observer would be justified in forming an estimate of the amount that a percussion burst was over or short.

Let us take the opposite extreme where the target is on a vertical surface (fig. 13). The actual distance that the percussion hit is short of the target is evidently no measure of the amount of increase of range required to reach the target.

The normal target will be in a situation which lies between the two just illustrated; that is, the ground about it will slope more or less.

(Fig. 12)



Suppose that a percussion hit is seen to be short at *a* (fig. 14). It is evident that if the ground had been level the shot would have struck at *b* and therefore that *bT* is the increase of range required to reach the target and not *aT*.

Even the report of an auxiliary observing party on the flank to the effect that the round struck 100 yards short, would be of little value in this case.

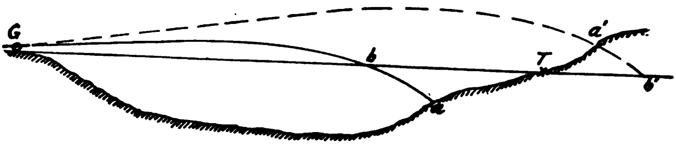
(Fig. 13)

If a shot struck at *a′* the actual decrease in range required would be *b′T* and not *a′T*.

Now, take the case where the target is behind a crest (fig. 15). If a percussion hit were at *a* it would probably not be seen at all from the guns but an observing party on the flank might report it 400 yards over, whereas the range for the next round needs to be decreased only by the distance *Tb*.

As this last situation and the preceding one are the usual ones for targets, it will be seen that the observer at the guns is able to tell very little about how much a burst is over or short. He should, therefore, stick closely to the rule of changing his range 400 yards for the second round, even when assisted by reports from an auxiliary observing party.

(Fig. 14)



In the examination of target records officers frequently demand an explanation when, the range set on the sights having been increased 400 yards, the change in the burst interval did not even approximately correspond. It will be seen from the above that it should not correspond except when the target is on level ground whose plane passes through the guns.

(Fig. 15)

From the above we might deduce the principle that for percussion hits on ground sloping toward the guns the burst interval will be less than the change of range required to hit the target, and that for percussion hits on ground sloping away from the guns the burst interval will be greater than the required change of range.

As these slopes are seldom regular, perhaps it would be better to make the deduction that not much can be told by the observer as to

the *amount* of the over or short; he should be satisfied if he is able to say that he is surely over or that he is surely short.

Beginners should always follow the rule of the 400-yards change. They will be surprised at the number of times it will keep them out of difficulties.

74. Ranging by time bursts.—Ranging by means of percussion projectiles is often very difficult on account of lost rounds.

One of the most annoying things is a deep ravine in front of the target, whose existence has not been discovered. Rounds falling into such a ravine may be sensed as over, either because they are not seen at all or because the smoke, when it does rise into the view, is so thin that the target is seen through it and judged to be in front of it.

Another cause of lost rounds with percussion fire is soft, marshy ground which swallows up the projectiles, while still another is ground covered with dense brush or tropical growth which imprisons the smoke.

If the first rounds fired are lost the battery commander is all at sea, and if he sticks to percussion fire has to feel aimlessly about until he gets a burst that can be seen.

Until the adoption of the present fuse setter ranging was habitually done with percussion projectiles, but that instrument supplies a ready means for avoiding the pitfalls of percussion ranging.

The theoretical effect of the fuse setter is to place all of the bursts in a plane passing through the gun and the target and normal to the plane of fire. In this discussion this plane will be called the zero plane. The corrector furnishes means of adjusting the heights of burst so as to bring them into this plane, if conditions are not normal, or to any desired distance above such plane for ranging or for fire for effect. The theoretical result of placing the burst in this plane for ranging is that the bursts appear, relatively to the target, as percussion bursts would appear if the target and guns were on level ground. The distances of the bursts from the target are then quite independent of the actual form of the ground.

This system is practicable only with a fuse which burns with reasonable regularity, and a fuse setter in which the setting is always that due to the range, modified by the corrector for the various conditions of the firing.

While theoretically the effect of the fuse setter is to place all of the bursts in one plane, it will be readily understood that in practice many bursts will be a little above or below this plane. The mean

point of burst of a series of shrapnel can, however, be brought into this plane. If the average variation of the fuse is small, the smoke of burst, spreading out in all directions from the bursting point, will conceal the target, or the target will appear silhouetted against it if the direction is properly adjusted. Moreover all bursts, whether air or percussion, that appear below a target which is on a crest are manifestly short. The only rounds which the observer may not judge as short or over are those bursting so high that no portion of the smoke ball reaches down to the target.

As the bracket is narrowed down and the bursts occur near the target a certain proportion of the bursts will be on graze, due to the fact that the ground approaches the zero plane at this point; any irregularities of burst cause a certain percentage of the fuses to burst below the plane.

Percussion bursts may also occur at other points along the range where the ground is near to or above the zero plane; unless such percussion hits bracket the target they do not indicate that the proper range has been obtained.

75. Height of burst for ranging.—In practice, time bursts for ranging are placed above the zero plane, so that they will appear at a height of one mil above the target as seen from a point near the guns.

The adoption of the one-mil height of burst of fuses during the ranging process is based upon the following analysis: To assist observation the smoke ball must be silhouetted against or silhouetted by the target; at short and medium ranges the one-mil height is admirably suited to such purpose, as the diameter of the smoke ball immediately after the time burst is about 4 yards. At long ranges the one-mil height of burst is theoretically too large. An incident to the practice of using the one-mil height of burst in ranging is the resulting shrapnel effect.

For short and medium ranges this slight elevation of the bursting point does not produce an undue percentage of bursts too high for purposes of observation, but for long ranges it may be advantageous to use a little lower corrector, as the one-mil height of burst at such ranges corresponds to a greater distance above the plane; furthermore, observation is more difficult on account of the distance.

In adjusting the mean height of burst to any plane account must be taken of the percussion bursts as well as of the air bursts, since the percussion bursts would have been low-time bursts with the ground

out of the way. The occurrence of an average of one percussion burst in four shots is an indication that the proper height of burst for adjustment has been obtained.

Estimating the mean height of burst by observing only the air bursts of a group of shots which also contains percussion hits is an erroneous method.

The proper method of observing the mean height of burst is similar to the method of observation of the range. That is, the observer should endeavor to determine whether the mean point is above or below the desired plane. When all of the bursts of the group are in the air and are closely grouped, it then becomes practicable to make a good estimate of the amount of correction necessary.

If fuses are poor ranging with time fire will be less satisfactory, but some advantage may still be gained from it, since with a low corrector a portion of time bursts will still be seen and many of the lost rounds which would result from percussion ranging will still be avoided.

Ranging with time fire has also the advantage that during the bracketing process the action of the fuse is observed and corrected, so that the proper corrector for fire for effect will be known as soon as the range is obtained. As time fire is used for effect in the majority of cases this is a considerable advantage.

Observations on air bursts from auxiliary stations on the flanks of the line of fire give more reliable information than do similar observations on percussion bursts. The location of the percussion burst is, as we have seen, dependent upon the form of the ground, whereas that of the time burst is independent of the form of the ground. Furthermore the percussion bursts are dependent upon the laying of the gun in elevation. If, for example, a gunner (having misunderstood the range) laid 100 yards too high, the percussion burst would be farther from the gun than it should be and, even if the firing were over level ground, the burst interval reported by the observing party would not be that due to the range ordered at the guns. If, on the other hand, a time burst be considered, it will be seen that the effect of the form of the ground will be eliminated and that the effect of the faulty laying will be to place the burst higher in the air, but with the same burst interval that it would have had if the gun had been correctly laid. The burst interval reported will be correct and the gunner's error will be detected.

Large errors in fuse setting are rare and are easily detected, while ordinary variations in setting are very small, so that variations in burst interval due to the fuse are reduced nearly to the error of the fuse itself.

The error of the fuse now in use is about equal to the error of the gun; therefore since the error of the gun and of the gunner and the influence of the form of the ground on the burst interval are eliminated in ranging with time bursts, the error of the fuse only being introduced, much better results should be obtained from this method.

In all ranging the officer conducting the fire should depend first of all on seeing whether the ball of smoke produced by the bursting projectile is short of or beyond the target.

There are other means of judging the range, such as observing the strike of shrapnel case, noting the dust knocked up by shrapnel balls, etc. All such indications are dependent on the conditions of the ground about the target and should be considered only as secondary matters to be noted when it can be done without diverting the officer's attention from the main reliance.

Officers whose firing experience is confined to a single firing ground are prone to place too much reliance on such of these secondary indications as are continually available on that ground.

Chapter XI.

PREPARATION AND CONDUCT OF FIRE.

76. General remarks.—The preceding chapters have dealt, in a simple manner, with the theory of gunnery as applied to the 3-inch field artillery matériel. It is assumed that the student has reviewed the Drill Regulations and the handbook. Even without having handled the plant, he should be impressed with its power and flexibility and the possibility of subordinating such weapon to intelligent control. It is no small matter to contemplate the responsibility of conducting fire during times of actual stress, where performances are almost wholly based upon previous instruction in problems where such stress is lacking.

The officer conducting the fire—and every officer in an artillery command should be able to replace him—has no time during stress for reposeful judicial action. He must do something, do that something quickly, and do it right. For this reason a proper training and much practice in time of peace become most important for him.

It is not held that all the matter contained in the preceding chapters of this volume is absolutely essential to the success of an individual field artillery commander in time of war. It is maintained, however, that study of the profession as here set forth will greatly assist in the understanding of the Drill Regulations.

77. Axioms in the profession.—As is the case among leaders of other professions, there are many points upon which eminent field artillerymen disagree. This disagreement is a form of intellectual activity, as a result of which acceptable and agreeable professional notions are evolved. These notions become the professional axioms—the common meeting point—of all enthusiastic artillerymen harassed by temporary disagreements upon subjects less vitally important. The Drill Regulations are constructed about the professional axioms. In particular, the pages on preparation and conduct of fire and those concerning artillery in the field should be analyzed most closely. Fire action is the only thing that justifies the existence of the arm.

(a) One of the first requirements is to occupy a position without the knowledge of the enemy; opening fire should surprise him.—It is almost impossible to measure the importance

of this requirement. In a position not yet revealed to the enemy, preparations for opening fire may be made with a fair degree of coolness and with great speed and accuracy. Even though it be not possible to provide for subsequent phases of the action, the advantage secured by surprising an enemy should continue until the nature of the problem is changed by the introduction of other elements. The history of warfare is full of incidents illustrating the value of action by surprise.

(b) **The time from first round to effective shrapnel fire should be a minimum.**—The total time which elapses from the instant of firing the opening round to the first effective round is made up of several elements, as follows:

Time of flight of first round.
Time consumed in observation of first round.
Time consumed in determining, announcing, and applying corrections based upon observation of first round.
Time consumed in bracketing.

The officer conducting the fire has no control over the projectile's time of flight. In so far as ranging is concerned this time is lost. The time consumed in observation of fire becomes more nearly a minimum as he becomes more adept in the use of his plant. A careful study of the chapter on ranging will reveal many points of value to an observer. Experience, however, is the only really satisfactory way to acquire an aptitude for rapid and accurate judgment in the most important art of fire observation.

The time consumed in determining the corrections to be applied before subsequent rounds may be delivered should be negligible in the case of officers even reasonably prepared for their duties. The parallax method is rapid as well as simple, and a well-instructed, conscientious officer should feel humiliated if time were lost in making unnecessary changes.

In the great majority of cases bracketing is necessary; even where the initial round is observed at the target, verifying rounds are necessary; by skill proceeding from study, thoughtful assimilation of the fundamentals, and above all from experience may the important time from opening fire to the first effective shrapnel round be reduced to a minimum.

(c) **The expenditure of ammunition in the accomplishment of a given purpose should be a minimum.**—One of the characteristic properties of modern field artillery is rapidity of fire. By virtue of this mechanical function it is possible to bring a crushing fire to

bear upon a vulnerable enemy before he can escape from its action. Limiting the application of rapidity of fire is the necessity for conserving ammunition, hence the rule above. Drill Regulations state: "*It is made the duty of every field artillery commander to exercise constant and unremitting care to economize ammunition.*" The chapter on ranging prescribes methods by which ammunition may be saved during the preliminaries to fire for effect. It is possible to prescribe definite rules leading to a fairly economical adjustment of fire, but when fire for effect begins the officer conducting the fire alone can compare his expenditures with the observed effect. As stated in Chapter I, the limit of the power of light field artillery has been reached when opposing personnel is being annihilated, when opposing matériel of like power is being destroyed and when the fire from moderately entrenched positions is being neutralized. Generally speaking, the officer conducting the fire should be guided in his choice of a method of fire by the desirability of getting a sufficient effect as quickly and as surely as possible. Fire should cease as soon as the desired effect is produced; the rate of fire and therefore the amount of ammunition expended should be commensurate with the object to be obtained.

78. Effect as a function of ammunition expended.—Referring to paragraph 68,

$$n=\frac{\log (l-z)}{\log (l-x)}$$

in which n is the number of rounds necessary to put out of action a certain portion, z per cent, of the target. Suppose x to equal 0.10; then, in order to put out of action 50 per cent of the target, $z=0.50$

$$n=\frac{\log 0.50}{\log 0.90}=6.57 \text{ rounds}$$

if $z=0.60$	$n=8.5$
$z=.70$	$n=11.4$
$z=.80$	$n=15.3$
$z=.90$	$n=21.8$

It will be seen that after a certain number of rounds the killing effect is hardly commensurate with the expenditure of ammunition. It may, however, be necessary to continue the fire in order to keep a previously overwhelmed though possibly active enemy pinned to the earth. The amount of ammunition to be expended in the accomplishment of a given purpose is ordinarily not capable of predetermination; the officer conducting the fire must regulate it in accordance with existing conditions.

EXPLOSIVES.

PART II.—EXPLOSIVES.

CHAPTER I.

EXPLOSIVES.

1. General remarks.—The power due to the action of which the projectile is propelled from the gun is present in the powder charge contained in the cartridge case.

This powder is ignited by means of a percussion primer, is converted into gas, and in the act of expanding forces the projectile through the bore of the gun with a rapidly increasing velocity. In the case of propelling charges the combustion is gradual, gas being evolved by the burning powder during all or nearly all of the time of passage of the projectile through the bore of the gun. In the 3-inch field gun this time amounts to about two-tenths of a second, or that during which a stone would fall about 8 inches under the action of gravity.

2. Nature of combustion.—The phenomena of combustion are found variously illustrated in nature. The more noticeable processes in which a combustible is combined with a supporter of combustion are attended with a production of heat or light, or frequently both. There are processes of combustion involving considerable time, as an example, the decay of a tree; such action is as truly combustion as is the burning of gas or coal.

When the hydrogen and carbon of which combustibles are mainly formed are so heated as to commence to combine with atmospheric oxygen, the process is a gradual one. The air in the immediate vicinity is first utilized, and as the oxygen it contains is expended, more rushes in until all the hydrogen is converted to water, and the carbon into carbon monoxide and carbon dioxide.

It should be understood, at this point of the discussion, that the chemical action just described develops power. In the case of the decaying tree such power may not be utilized, but that contained in coal, oil, or gas is subject to continuous industrial demand.

3. Nature of an explosion.—If by any means the supply of the supporter of combustion be increased, combustion is rendered more rapid and consequently more violent. Generally speaking, explosion may be defined as a sudden and violent increase in the volume of a substance. Chemically, explosion is the rapid conversion of a solid or liquid to the gaseous state, or the instantaneous, or nearly instantaneous, combination of two or more gases accompanied by increase of volume.

Certain compounds contain a considerable quantity of oxygen, with which they are very ready to part when heated, and if, therefore, one of these materials be intimately mixed with a readily oxidizable substance, it is clear that combustion will be more rapid than in the case where oxygen must be obtained gradually from the air. Explosion is, therefore, produced by a very rapid combustion.

4. Effect of confinement.—If an explosive mixture or an explosive compound be ignited and left to burn in air, in the usual case an appreciable time will be necessary for its combustion. The burning surfaces, exposed to the air, will be relieved from their hot gases as soon as formed; these burning gases will have no tendency to penetrate the mass of the explosive, but will blow away along the easiest path.

If, however, such mixture or compound be confined in a closed vessel a high degree of pressure is soon set up. This pressure increases the rate of burning, the burning in its turn increases the pressure, and so on, the result being that the process of combustion is completed in a time almost inappreciably small.

5. Detonation.—We have seen that in the process of combustion the chemical reaction takes place slowly, whereas in explosion such reaction occupies a smaller time. An explosion starts with the explosion of a single particle and takes place progressively from particle to particle until the phenomenon is complete. Detonation is effected with greater rapidity than is explosion; apparently there is no progression from particle to particle, but an instantaneous conversion of all of the explosive compound into gases.

The difference in the rapidity of reaction has given rise to the division of explosives into two groups, high explosives and progressive explosives. The principal high explosives in general use are nitroglycerin, the dynamites, guncotton, picric acid and its salts, trinitro-toluol, and the fulminate of mercury. The various gunpowders

are progressive explosives. Gunpowder is a term covering charcoal and smokeless powders used as propellants in service or sporting weapons.

6. Charcoal powders.—The black gunpowder used as a base charge for shrapnel and in the preparation of igniters is a mechanical mixture of niter (potassium nitrate), charcoal, and sulphur in the proportions, approximately, of 75 parts niter, 15 charcoal, and 10 sulphur. Niter furnishes the oxygen in the above mixture and charcoal is the combustible; sulphur is used in gunpowder to lower the point of ignition of the mixture and to give density to the grain.

In the manufacture of black powder the ingredients are intimately mixed, incorporation taking place in a wheel mill, under heavy iron rollers. A cake is formed by pressing, then broken up into grains. The grains are rumbled in wooden barrels where they are glazed, either alone or with a small quantity of graphite. The powder is thoroughly blended to overcome as far as possible irregularities in manufacture.

Black meal powder used in the manufacture of time trains for fuses is a charcoal powder, usually of slightly different percentages of niter, sulphur, and charcoal, and in some cases containing a slowing ingredient as, for instance, barium nitrate.

7. Smokeless powders.—There are two classes of smokeless powders used in our service, nitro-glycerin powder and nitrocellulose powder.

Both classes of powders are made from guncotton. The nitro-glycerin powder is so called from the fact that it contains a certain amount of nitro-glycerin—in our small-arms powder about 30 per cent by weight. The principal merit of smokeless powder is, of course, its invisibility, such advantage more than counterbalancing its increased cost and time consuming complexities of manufacture. The length of time required for the drying of guncotton powders has caused much concern. In time of war this operation would greatly retard the output of powder.

The materials and processes employed in the manufacture of smokeless powder are prescribed by the Ordnance Department in rigid specifications, and the manufacture in all its stages is under careful inspection. The proof of the powder consists of tests made to determine its ballistic qualities, its uniformity, and its stability under various conditions. In the 3-inch field gun a muzzle velocity of

1,700 feet per second must be obtained with a pressure not exceeding, approximately, 30,000 pounds per square inch; the extreme variation in velocity must not exceed 1 per cent of the required velocity.

8. Form and size of grains.—The most desirable form of powder grain is one which gives off gas slowly at first, starting the projectile before a high pressure is reached, and then with an increased burning surface and a more rapid evolution of gas maintaining the pressure behind the projectile as it moves down the bore. Carrying out this idea of a proper grain, the cannon powder in our service is formed into cylindrical grains with seven longitudinal perforations, one central and the other six equally distributed midway between the center of the grain and its circumference. In other services cannon powders are made into grains of various shapes. Cubes, solid and tubular rods of circular cross section, flat strips, and rolled sheets are among other practicable forms.[1]

Generally speaking, the length and diameter of the grain vary in powders for different guns, the size increasing with the caliber of the gun. It has been found that the rate of burning of powders is affected by their density; this principle is utilized in the manufacture of time trains for fuses and in delay action primers. In outlining the progress in the manufacture of gunpowders and the development of the fundamental principles upon which our service powders are designed, Maj. Lissak (Ord. Dept., U. S. A., retired) states essentially:

"No marked improvement was made in gunpowder until 1860, when the principle of progressive combustion of powder was discovered, and that the rate of combustion, and consequently the pressure exerted in the gun, could be controlled by compressing the fine grained powder previously used into larger grains of greater density. The rate or velocity of combustion was found to diminish as the density of the powder increased. The increase in size of grain diminished the surface inflamed, and the increased density diminished the rate of combustion, so that, in the new form, the powder evolved less gas in the first instants of combustion, and the evolution of gas continued as the projectile moved through the bore. By these means higher muzzle velocities were obtained with lower maximum pressures. To obtain a progressively increasing surface the perforated

[1] For computations concerning the action of various forms of powder grains, see Lissak's Ordnance and Gunnery (John Wiley & Sons, 1907).

grain was proposed, and the prismatic form as the most convenient for building into charges. Powder was thereafter made into grains of size suitable to the gun for which intended, small grained powder for guns of small caliber, and large grained powder for the larger guns, the powders of regular granulation, such as the cubical, hexagonal and sphero-hexagonal, came into use, and finally for the larger guns the prismatic powder in the form of perforated hexagonal prisms. * * * A still further advance in the improvement of powders was brought about in 1886 by the introduction of smokeless powders. These powders are chemical compounds and not mechanical mixtures like the charcoal powders; they burn more slowly than the charcoal powders and produce practically no smoke."

The grain used in the 3-inch field gun is a cylindrical, multiperforated grain about $\frac{3}{8}$-inch long and $\frac{1}{5}$-inch wide. A description of the service powder charge will be found in the handbook.

9. Manufacture of smokeless powders.—As stated previously, military powder is usually one of two general types—nitrocellulose or nitroglycerin powder. In this country the nitrocellulose powders have been adopted for cannon; in foreign countries both kinds are used; in England, for instance, cordite, a nitoglycerin powder, is the principal propellant. Generally speaking, the manufacture of either of the two classes of smokeless powders involves the same functions, i. e., that of nitrating some supporter of combustion and forming the resulting substance into grains properly designed for the weapon for which intended. In nitrocellulose powder short cotton fiber furnishes the carbon or combustible, whereas glycerin furnishes a part of the combustible in the nitroglycerin powders. Guncotton or nitrocellulose is formed by acting upon cotton with nitric and sulphuric acid; the function of the latter acid is to combine with such water as might otherwise dilute the nitric acid, thus preventing the proper nitration of the cotton. The nitrated cotton is then placed in a solvent (usually ether-alcohol or acetone), by which process it is colloided or formed into a tough horny mass. The colloid is pressed through dies containing pins, which form the perforations in the powder grain. The colloid comes through the dies in long strings, having the appearance of macaroni; these strings are cut up into grains which are sent through a process for removing and recovering the solvent. After drying to a certain standard a lot is ready for proof; such proof consists in an inspection of the physical dimensions of the grain—length, diameter, thickness of web, density,

strength to resist compresssion—as well as firing tests to determine its velocity for certain pressures and charges, and a laboratory test to determine its composition and probable behavior in storage.

10. Flashless powders.—In recent years the belief has grown that military powders should be not only smokeless but flashless as well, so as not to disclose the position of a firing unit. The ordinary forms of smokeless powders are not usually flashless. Smokeless powder has a very high temperature of explosion, and when the projectile leaves the gun the strong luminous flash, together with unburnt slivers of powder coming out with the blast, are clearly visible for great distances. The problem has been fairly well solved; the Field Artillery Board has experimented with a reasonably satisfactory flashless powder, and, comparing its visibility with that of service powders, has recommended:

(*a*) That the present service powder has a flash of such brilliance as to make dismounted and mounted defilade practically useless so far as concealment is concerned.

(*b*) That if flashless powders can be made to give as good ballistic results as the service powders they are to be preferred.

It is believed that before long the service will be supplied with a powder quite as good ballistically as the present powder and at the same time practically flashless.

11. Other progressive powders.—The manufacture of military powders has had no easy problem to solve; the nitrocellulose and nitroglycerin powders have been not altogether satisfactory, in that their stability is not beyond question, except for comparatively short periods of time and under good storage conditions. By extreme care the manufacturing processes have been brought to a great degree of refinement; investigation has led to the adoption of certain stabilizers or indicators of stability; fundamentally, however, there are objections to the use of nitrocellulose for service powders. This material is complex, and therefore liable to form unstable compounds; under the influence of heat and moisture the nitrocellulose is most apt to decompose. The question of a war reserve of powders, based upon nitrocotton or nitroglycerin, is limited by their tendency to deteriorate, whereas the problem of supplying such powders in times of stress is greatly affected by the time consumed in manufacture and drying. Manufacturers, inventors, and powder experts have been, and are now, engaged in solving the problem of military

powders; almost every supporter of combustion has been variously combined with different combustibles in the hope of ultimately discovering a proper powder.

12. Firing a field gun.—When the percussion primer in the base of the cartridge case is fired a flame is shot into the propelling charge. This flame, assisted by a small charge of black rifle powder placed in front of the propelling charge, causes ignition of the powder grains. As gas is evolved the pressure rises until it becomes sufficient to move the projectile against the resistance of the rifling; the projectile begins to move, and its motion is accelerated by the pressure of the increasing and expanding powder gases until a maximum speed is attained at or near the muzzle.

CHAPTER II.

HIGH EXPLOSIVES.

13. General considerations.—It has been seen that the special purpose of the 3-inch field gun is attack on personnel. Where, however, such personnel is protected by overhead and head cover, it must be exposed before it can be affected by the shrapnel balls. For the destruction of walls, parapets, and other obstacles high explosives are necessary.

14. Subdivision according to use.—For military purposes high explosives are used to produce demolitions:

(*a*) At relatively long distances from our troops; the material to be destroyed being in the actual or probable possession of the enemy.

(*b*) Within our lines; the material to be destroyed being in our possession and the destruction necessary in order to cause loss or annoyance to the enemy or to facilitate our own progress.

In the first case it is usual to employ high explosive projectiles, delivering them at gun ranges for effect upon impact; in the second case it is usual to carry the explosive to the desired point, where it is used in accordance with methods set forth in the Manual of Military Field Engineering.

Except when absolutely necessary, artillery must not be used for purposes of demolition other than those in which the object to be accomplished is the exposure of personnel or the destruction of other artillery.

15. Military high explosives.—High explosives for military use should be:

(*a*) Stable and not easily affected by reasonable variations of temperature and moisture; shell fillers should not form unstable compounds (metallic salts).

(*b*) Insensitive to the usual shocks of transportation; shell fillers should be safe under the action of firing stresses and should not detonate merely as a result of impact against obstacles.

(*c*) Not difficult to detonate with properly designed detonators.

(*d*) Quick enough to give good results when confined; shell fillers should cause the projectile to break into fragments just sufficiently large to put a man or horse out of action.

(*e*) Convenient in form and consistency for packing and loading and for making into charges of different weights.

16. Shell fillers.—In our service picric acid, explosive "D," and tri-nitro-toluol are used as shell fillers. High explosive shell contain explosive "D," with a small charge of picric acid surrounding the detonator. High explosive shrapnel has a matrix of tri-nitro-toluol, which is detonated upon impact by the preliminary detonation of mercury fulminate and picric acid; tri-nitro-toluol may also be detonated with a fulminate detonator augmented by a small amount of tri-nitro-toluol in loose crystals.

17. Picric acid.—Picric acid, or tri-nitro-phenol, is formed by acting upon phenol with nitric acid. As a shell filler it may be pressed into the explosive cavity or melted and poured in; as it forms unstable metallic salts, it must not be assembled in projectiles until the cavity is thoroughly coated with a nonmetallic paint. Picric acid is the basis of many of the foreign shell fillers, as for instance, melinite, lyddite, shimose, ecrasite, etc. The difference in composition consists usually in the addition of an ingredient (camphor, nitro-naphthalene, dinitrotoluene, etc.) to reduce the melting point.

17. Trinitrotoluol.—Trinitrotoluol is formed by acting upon toluene with nitric acid. In its pure form it may be used as a shell filler without fear of the formation of unstable compounds; hence it has been selected as a matrix surrounding the shrapnel balls. Its use is general in high explosive shrapnel.

18. Other military explosives.—There are a number of satisfactory high explosives for military use other than as shell fillers. These explosives conform to the requirements as to stability, etc. The one most easily obtained when needed would probably be used.

Such explosives are:

Gun cotton;
Nitroglycerin;
The dynamites;
Rack a rock, etc.

Gun cotton or nitrocellulose is formed by acting upon cotton with nitric acid; nitroglycerin is formed by acting upon glycerin

with nitric acid. Due to the danger involved in the transportation of nitroglycerin, an absorbent was found for it so that it could be transported in solid form. When such absorbent is inert, it adds nothing to the force of the nitroglycerin; when an active absorbent, as for instance potassium nitrate, is used, the explosion is more violent.

Rack a rock is one of the so-called safety mixtures; in reality, the components for the manufacture of this high explosive are transported separately to the place where needed; at this place the mixture is made. The components are powdered chlorate of potassium and nitrobenzene; the chlorate being carried in small cloth cartridges, to be dipped into the liquid nitrobenezene before using.

19. Fulminate of mercury.—This high explosive is used in detonators and is formed by the action of nitric acid upon the metal mercury. It is a very powerful explosive and is the basis of the manufacture of numerous types of blasting caps and detonators. Used in service detonators, it is combined with an alcoholic solution of shellac and assembled under a pressure somewhat exceeding the probable pressure resulting from the shock of discharge. When the shell filler is properly confined and the detonator correctly proportioned the detonation should be perfect; dense black smoke is a characteristic of such detonation.

Lead nitride has been proposed as a substitute for mercury fulminate; both trinitrotoluene and trinitromethylaniline have been used in the manufacture of detonators.

Appendix A.

THE GREEK ALPHABET.

The Greek alphabet is here inserted to aid those who are not already familiar with it, in reading the parts of the text in which its letters occur.

Letters.	Names.	Letters.	Names.
Α α	Alpha.	Ν ν	Nu.
Β β	Beta.	Ξ ξ	Xi.
Γ γ	Gamma.	Ο ο	Omicron.
Δ δ	Delta.	Π π	Pi.
Ε ε	Epsilon.	Ρ ρ	Rho.
Ζ ζ	Zeta.	Σ σ ς	Sigma.
Η η	Eta.	Τ τ	Tau.
Θ ϑ θ	Theta.	Υ υ	Upsilon.
Ι ι	Iota.	Φ φ	Phi.
Κ κ	Kappa.	Χ χ	Chi.
Λ λ	Lambda.	Ψ ψ	Psi.
Μ μ	Mu.	Ω ω	Omega.

APPENDIX B.

Range table for 3-inch field gun.

Range.	Angle of departure.	Angle of departure.	Angle of elevation.	One minute, in yards of range.	One mil, in yards of range.	ΔX for $\pm$ 10 f. s. M. V.	ΔX for $\Delta C = \pm \frac{1}{10}$.
Yds.	° ′	*Mils.*	° ′			*Yds.*	*Yds.*
100	0 05.9	1.7	0 00.2	16.7	56	1.08	0.2
200	0 11.9	3.5	0 06.2	15.6	52	1.9	0.8
300	0 18.3	5.4	0 13.6	15.2	50	2.8	1.7
400	0 24.9	7.4	0 19.3	14.5	48	3.7	3.0
500	**0 31.9**	**9.5**	**0 26.3**	**13.9**	**46**	**4.6**	**4.6**
600	0 39.0	11.6	0 33.4	13.3	44	5.5	6.9
700	0 46.5	13.8	0 41.0	12.7	42	6.4	9.4
800	0 54.4	16.1	0 48.8	12.2	41	7.3	12.1
900	1 02.6	18.5	0 57.0	11.6	40	8.1	15.0
1,000	**1 11.2**	**21.0**	**1 05.6**	**11.2**	**38**	**8.8**	**18.1**
1,100	1 20.2	23.6	1 14.5	10.8	36	9.5	21.7
1,200	1 29.4	26.4	1 23.8	10.4	35	10.2	25.3
1,300	1 39.0	29.3	1 33.4	10.0	33	10.8	29.1
1,400	1 49.0	32.3	1 43.8	9.6	32	11.4	32.9
1,500	**1 59.4**	**35.4**	**1 53.8**	**9.4**	**31**	**12.1**	**36.9**
1,600	2 10.3	38.6	2 04.7	9.2	31	12.7	41.2
1,700	2 21.5	41.9	2 15.9	9.0	30	13.3	45.5
1,800	2 32.9	45.3	2 27.3	8.8	29	13.9	49.8
1,900	2 44.7	48.8	2 39.1	8.5	28	14.5	54.1
2,000	**2 56.7**	**52.4**	**2 51.1**	**8.3**	**27**	**15.0**	**58.4**
2,100	3 09.3	56.1	3 03.7	8.0	27	15.5	62.9
2,200	3 22.1	59.9	3 16.5	7.8	26	16.0	67.4
2,300	3 35.1	63.8	3 29.5	7.7	26	16.4	71.9
2,400	3 48.3	67.7	3 42.7	7.6	25	16.9	76.5
2,500	**4 01.8**	**71.7**	**3 56.2**	**7.4**	**25**	**17.3**	**81.0**
2,600	4 15.4	75.7	4 08.7	7.3	24	17.7	85.3
2,700	4 29.1	79.8	4 22.7	7.1	24	18.1	89.7
2,800	4 43.1	83.9	4 36.7	7.0	23	18.5	94.1
2,900	4 57.5	88.1	4 50.9	6.9	23	18.9	98.5
3,000	**5 12.0**	**92.4**	**5 05.4**	**6.8**	**23**	**19.2**	**102.9**

Appendix B.

Range table for 3-inch field gun.

ΔX for wind 10 miles per hour.	Drift.	Deviation for 10 miles cross wind.	Angle of fall.	Slope of fall.	Time of flight.	Terminal velocity.	Maximum ordinate.
Yds.	*Yds.*	*Yds.*	° ′	*1 on—*	*Secs.*	*F. S.*	*Feet.*
0.01	0.4	0.04	0 05.8	592.7	0.18	1,647.0	0.2
0.06	0.7	0.08	0 12.2	281.1	0.36	1,595.4	0.8
0.12	1.0	0.12	0 19.3	178.0	0.55	1,547.0	1.7
0.26	1.2	0.16	0 27.0	127.3	0.75	1,500.0	2.9
0.43	**1.5**	**0.21**	**0 35.3**	**99.9**	**0.96**	**1,456.0**	**4.3**
0.65	1.7	0.27	0 44.2	87.5	1.17	1,414.0	6.0
0.89	1.9	0.32	0 53.9	75.2	1.38	1,374.2	8.1
1.20	2.1	0.38	1 04.3	63.1	1.60	1,337.3	10.7
1.50	2.4	0.44	1 15.5	51.3	1.83	1,303.0	13.8
1.80	**2.6**	**0.50**	**1 27.3**	**39.4**	**2.07**	**1,270.2**	**17.3**
2.20	2.8	0.67	1 40.8	35.8	2.31	1,242.0	21.7
2.60	3.1	0.85	1 54.6	32.0	2.56	1,217.0	26.6
3.10	3.3	1.10	2 08.9	27.2	2.81	1,193.0	32.1
3.50	3.6	1.30	2 23.6	24.5	3.07	1,168.0	38.3
4.00	**3.9**	**1.50**	**2 38.6**	**21.6**	**3.34**	**1,145.0**	**45.3**
4.50	4.2	1.70	2 55.6	19.8	3.61	1,121.0	53.1
5.10	4.4	2.00	3 13.0	18.1	3.89	1,099.0	61.8
5.60	4.7	2.30	3 30.8	16.5	4.17	1,078.0	71.4
6.20	4.9	2.60	3 49.0	15.1	4.46	1,057.0	81.8
6.80	**5.1**	**2.90**	**4 07.6**	**13.9**	**4.75**	**1,038.0**	**93.1**
7.40	5.3	3.20	4 26.9	12.9	5.05	1,020.0	105.3
8.00	5.6	3.50	4 46.7	12.1	5.35	1,002.0	118.4
8.60	5.8	3.90	5 06.9	11.3	5.65	986.0	132.5
9.30	6.2	4.30	5 27.6	10.5	5.95	971.0	147.5
9.90	**6.6**	**4.60**	**5 48.8**	**9.8**	**6.26**	**958.0**	**163.5**
10.60	7.0	5.00	6 10.4	9.3	6.57	946.0	180.0
11.20	7.5	5.40	6 32.5	8.8	6.88	935.0	198.0
11.80	8.0	5.90	6 55.0	8.3	7.19	924.0	216.0
12.50	8.5	6.40	7 17.9	7.8	7.51	915.0	236.0
13.10	**9.1**	**6.90**	**7 41.2**	**7.4**	**7.83**	**906.0**	**257.0**

Range table for 3-inch field gun—Continued.

Range.	Angle of departure.	Angle of departure.	Angle of elevation.	One minute, in yards of range.	One mil, in yards of range.	$\triangle X$ for ± 10 f. s. M. V.	$\triangle X$ fo $C = \pm$
Yds.	° ′	*Mils.*	° ′			*Yds.*	*Yds*
3,100	5 26.6	96.8	5 20.0	6.7	22	19.5	107.
3,200	5 41.6	101.3	5 35.0	6.6	22	19.8	111.
3,300	5 56.9	105.9	5 50.3	6.5	22	20.1	115.
3,400	6 12.6	110.5	6 06.0	6.3	21	20.4	119.
3,500	**6 28.7**	**115.2**	**6 22.1**	**6.1**	**21**	**20.6**	**123.**
3,600	6 45.1	120.0	6 38.5	6.0	20	20.8	127.
3,700	7 01.9	124.9	6 55.2	5.9	20	21.0	131.
3,800	7 19.0	130.0	7 12.4	5.7	19	21.2	136.
3,900	7 36.5	135.2	7 29.8	5.6	19	21.4	140.
4,000	**7 54.2**	**140.5**	**7 47.5**	**5.5**	**18**	**21.6**	**144.**
4,100	8 12.3	145.9	8 05.9	5.4	18	21.8	149.
4,200	8 30.7	151.4	8 24.0	5.3	18	22.0	154.
4,300	8 49.5	157.0	8 42.9	5.2	17	22.2	159.4
4,400	9 08.6	162.6	9 01.9	5.2	17	22.4	164.4
4,500	**9 28.5**	**168.8**	**9 21.8**	**5.1**	**17**	**22.6**	**169.5**
4,600	9 47.7	174.1	9 41.9	5.0	17	22.8	174.8
4,700	10 07.8	180.0	10 02.0	4.9	16	23.0	180.1
4,800	10 28.2	186.0	10 22.4	4.8	16	23.2	185.4
4,900	10 49.0	192.2	10 43.2	4.7	16	23.4	190.8
5,000	**11 10.1**	**198.5**	**11 04.8**	**4.7**	**16**	**23.6**	**196.**
5,100	11 31.5	204.9	11 25.7	4.6	15	23.8	201.4
5,200	11 53.3	211.4	11 47.5	4.5	15	24.0	206.5
5,300	12 15.5	218.0	12 09.7	4.4	15	24.2	211.6
5,400	12 38.1	224.7	12 32.3	4.3	14	24.4	216.6
5,500	**13 01.1**	**231.5**	**12 55.3**	**4.3**	**14**	**24.6**	**221.7**
5,600	13 24.4	238.4	13 17.7	4.2	14	24.8	226.6
5,700	13 48.2	245.4	13 40.5	4.1	14	25.0	231.6
5,800	14 12.3	252.5	14 04.6	4.1	14	25.2	236.5
5,900	14 36.9	259.8	14 29.2	4.0	13	25.3	241.5
6,000	**15 01.8**	**267.2**	**14 54.1**	**4.0**	**13**	**25.5**	**246.6**
6,100	15 27.1	274.7	15 19.4	3.9	13	25.7	251.6
6,200	15 52.9	282.3	15 45.2	3.8	13	25.8	256.6
6,300	16 19.0	290.0	16 11.3	3.8	13	26.0	261.6
6,400	16 45.6	297.8	16 37.9	3.7	12	26.1	266.6
6,500	**17 12.6**	**305.8**	**17 04.9**	**3.7**	**12**	**26.2**	**271.6**

Range table for 3-inch field gun—Continued.

ΔX for wind 10 miles per hour.	Drift.	Deviation for 10 miles cross wind.	Angle of fall.	Slope of fall.	Time of flight.	Terminal velocity.	Maximum ordinate.
Yds.	*Yds.*	*Yds.*	° ′	*1 on—*	*Secs.*	*F. S.*	*Feet.*
13.80	9.8	7.40	8 04.2	7.1	8.15	899.0	279.0
14.40	10.6	8.00	8 28.0	6.7	8.47	892.0	302.0
15.00	11.6	8.60	8 52.5	6.4	8.80	886.0	326.0
15.70	12.6	9.20	9 17.7	6.1	9.13	879.0	351.0
16.40	**13.6**	**9.80**	**9 43.7**	**5.8**	**9.47**	**873.0**	**378.0**
17.00	14.7	10.50	10 10.4	5.6	9.82	865.0	406.0
17.70	15.7	11.10	10 37.6	5.2	10.17	858.0	436.0
18.40	16.6	11.80	11 05.4	5.0	10.53	851.0	468.0
19.20	17.5	12.50	11 33.9	4.8	10.89	844.0	501.0
19.90	**18.4**	**13.30**	**12 02.9**	**4.7**	**11.25**	**837.0**	**536.0**
20.70	19.3	14.00	12 32.6	4.5	11.62	830.0	572.0
21.60	20.1	14.80	13 02.9	4.3	11.99	824.0	610.0
22.40	20.9	15.60	13 33.8	4.1	12.37	818.0	649.0
23.20	21.7	16.40	14 05.2	4.0	12.75	812.0	689.0
24.00	**22.5**	**17.30**	**14 37.3**	**3.8**	**13.13**	**806.0**	**731.0**
25.00	23.4	18.20	15 09.9	3.7	13.52	800.0	775.0
26.00	24.4	19.10	15 43.1	3.6	13.92	795.0	822.0
27.00	25.3	20.00	16 16.8	3.4	14.32	789.0	871.0
28.00	26.3	20.90	16 51.1	3.3	14.72	784.0	922.0
29.00	**27.7**	**21.90**	**17 26.0**	**3.2**	**15.12**	**779.0**	**975.0**
29.80	29.2	22.80	18 01.9	3.1	15.52	774.0	1,029.0
30.70	31.1	23.80	18 38.2	3.0	15.92	770.0	1,085.0
31.50	33.4	24.80	19 14.8	2.9	16.32	765.0	1,143.0
32.40	36.0	25.80	19 51.7	2.8	16.73	761.0	1,202.0
33.40	**38.8**	**26.90**	**20 29.0**	**2.7**	**17.14**	**757.0**	**1,263.0**
34.40	41.8	28.00	21 06.3	2.6	17.56	753.0	1,326.0
35.50	45.0	29.10	21 44.1	2.5	18.00	750.0	1,391.0
36.60	48.8	30.30	22 22.5	2.4	18.44	747.0	1,458.0
37.70	51.8	31.60	23 01.6	2.3	18.89	743.0	1,527.0
38.80	**55.3**	**32.80**	**23 40.9**	**2.3**	**19.36**	**740.0**	**1,598.0**
39.90	59.0	34.20	24 20.9	2.2	19.85	737.0	1,672.0
41.10	62.5	35.60	25 01.5	2.2	20.35	733.0	1,748.0
42.30	66.1	37.00	25 42.7	2.1	20.86	730.0	1,827.0
43.60	69.5	38.80	26 24.5	2.1	21.38	727.0	1,908.0
44.80	**73.0**	**39.90**	**27 06.8**	**1.9**	**21.92**	**724.0**	**1,992.0**

Appendix C.

EXAMINATION QUESTIONS.

How is the force of recoil checked in the 3-inch field gun? What is the purpose of the counter-recoil buffer? Describe the mode of action of the counter-recoil buffer. What precautions should be taken in filling the cylinder?

What projectiles are used in the 3-inch field gun? Describe each kind.

The drill regulations prescribe that the gunner shall set off the range, even though he is only laying for direction. Why is this necessary?

What conditions must be fulfilled before the battery commander's telescope is in adjustment? Describe the methods of making the adjustment and show that the methods described accomplish the purpose.

What is the composition of black gunpowder? What is the purpose of each constituent?

Describe, in general terms, the process of manufacture of smokeless powder.

What is the purpose of the priming charge of black powder which is added to the smokeless powder charge?

What is the object of perforating the grains of smokeless powder?

What is the advantage of a "slow-burning" powder over a "quick-burning" powder? What is the difference between the action of a "high explosive" and that of a "propelling" charge?

When is a "correction for obliquity" necessary?

What is the principle of "the rigidity of the trajectory"? What is the practical effect of this principle in gunnery?

A battery is in position. A suitable observing station has been chosen in rear of the battery and on the prolongation of the line joining the right gun and the target. The range to the target from the observing station has been found to be 3,000 yards, the distance from the observing station to the gun is 100 yards. A suitable

aiming point has been selected and its distance from the observing station determined as 2,000 yards. Measurement of the angle at the observing station between the aiming point and the target gives 1,800 mils. What is the deflection of the right gun?

What are the mathematical operations performed by the "sliding scale" on the battery commander's ruler when it is used to determine the height of the trajectory at the mask?

A battery fires its first salvo and it is seen that all bursts are on graze. The battery commander wishes to adjust the height of bursts without changing the angle of site. By how much should he change the corrector? Why?

A battery is firing at a target the range of which is 5,000 yards. What change in range will be caused by a change in the angle of site of 15 mils?

What is the maximum slope of fall of the lower elements of the shrapnel sheaf at 3,000 yards range?

Define range, angle of departure, angle of site, remaining velocity.

What is the deflection of the right piece of a battery, using indirect laying, with an aiming point in front and 5,000 yards distant, the range being 4,000 yards, the observing station being on the left of the guns and 200 yards from the right gun, the angle measured at the observing station from the aiming point to target being 6,230? How did you get it?

What are the principal sources of error in field artillery service practice?

How would you determine in the general case whether you could fire over a mask? Would the projectiles clear the crest, if a battery was firing from a position 200 yards in rear of it, upon a target 2,000 yards from the gun, and having an angle of site of 315, the intervening crest being 24 feet above the guns?

If your B. C. telescope and B. C. ruler were both lost or unserviceable, how would you determine firing data for indirect laying?

What is the corrector used for? Does an increase of the corrector have any effect on the trajectory of a shrapnel? Within effective artillery ranges does a change of range have any effect on the corrector for the day?

Using the B. C. ruler, construct to scale on cross section paper the trajectory for range 3,500 yards.

What is the principal characteristic of a perfect detonation?

In the adjustment of fire, what times enter into the total time from opening fire to the delivery of the first effective shrapnel?

Why has the one mil height of burst during adjustment been adopted in our service? Is this height of burst correct for all ranges? Gives reasons for your answer.

What is the usual procedure in ranging? Why should changes of range less than 25 yards never be made?

Describe briefly what occurs when a gun is fired.

What are the principal errors affecting the accuracy of fire?

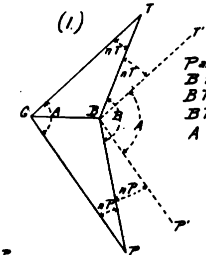
What is the 50 per cent zone?

What is the line of sight in indirect laying?

Construct on cross section paper the ground section of the cone of dispersion of a service shrapnel bursting at 3,500 yards range.

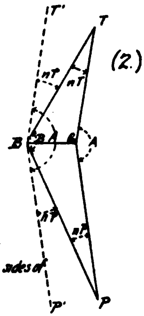
Appendix D

Geometrical illustration of parallax method



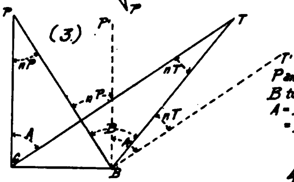
1st Case –

P and T on opposite sides of BG,
B to right of G
BT, parallel to GT
BP, parallel to GP
$A = B - nP - nT$
$\quad = B + n(-P - T)$



2d Case –

P and T on opposite sides of BG, B to left of G
$A = B + nP + nT$
$\quad = B - n(-P - T)$

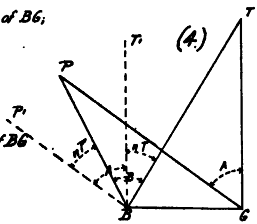


3d Case –

P and T on same side of BG;
B to right of G
$A = B - nP + nT$
$\quad = B - n(+P - T)$

4th. Case –

P and T on same side of BG
B to left of G
$A = B + nP - nT$
$\quad = B + n(+P - T)$



Summary

1. $A = B + n(-P - T)$
2. $\quad = B - n(-P - T)$
3. $\quad = B - n(+P - T)$
4. $\quad = B + n(+P - T)$